Spineless

Status and trends of the world's invertebrates

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Edited by Ben Collen, Monika Böhm, Rachael Kemp and Jonathan E. M. Baillie

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IUCN RED LIST

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THE IUCN RED LIST
OF THREATENED SPECIES™

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Cover photograph: Praying mantis (Mantodea) © George J. Reclos

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Foreword

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Status and trends of the world's invertebrates

The sheer diversity of invertebrate animals is astounding but few are large enough to really impose themselves on our senses, so much of this spectacular diversity has remained out of sight and out of mind in soils, in forest canopies, in coral reefs and in the ocean depths. Since the 1750s over 1.9 million species have been described globally and over 70% of these are invertebrates. Even today the discovery rate of new species is in the order of 16,000 to 20,000 per year, particularly in the tropics, and most, of course, are invertebrates. With over one million known species the insects dominate terrestrial and freshwater animal communities, but they never really made much of a mark in the oceans. In ocean ecosystems it is the molluscs and the crustaceans that are the richest in species and tend to dominate. Invertebrates are diverse, they are abundant and they are everywhere.

Invertebrates are one of the essential foundations of healthy ecosystems that we depend on: almost every marine fish that forms part of the human food chain will have fed on invertebrates at some time during its development, for example. We directly consume invertebrates, such as shellfish, or their products, such as honey, but our awareness of the importance of invertebrates has generally been low, even though we rely on invertebrates to pollinate our crops, to reprocess our waste, and to deliver a multitude of other services. This situation is now changing and research has also highlighted the importance of invertebrates as regulators of ecosystem processes.

Just like birds and mammals, invertebrate species are also under threat from anthropogenic change, but the priority for conservation has been the vertebrates. In Europe, the Bird and Habitat directives give a protection status to 1,140 animal species, of which 986 are vertebrates and 154 invertebrates. These figures represent 64.8% of the vertebrates but only 0.1% of the invertebrates present in Europe. Greater emphasis is now being placed on the invertebrates and this timely report outlines the importance of invertebrates to our habitats and ecosystems in addition to highlighting the conservation challenges that they face.

Invertebrates deserve to be higher up the conservation agenda and this report, produced by the Zoological Society of London, will both inform the wider debate and contribute to the discussion on priorities within the conservation community.

Geoff Boxshall FRS
Secretary, Zoological Society of London

Preface

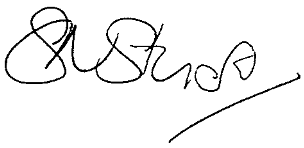
Foundations of biodiversity -
Status and trends of the world's invertebrates

Invertebrates make up the great majority of known species on earth – on land, in freshwater and in the oceans. Invertebrates are quite literally everywhere. And although we tend to take very little notice of them – and regard many as pests – we are also dependent upon them. Without invertebrates, we would lose much of the pollination services upon which agriculture depends. Without earthworms, the processes that spread organic matter through soil would be severely disrupted. Marine invertebrates, such as shrimps, prawns, crabs and squid, are important sources of protein for people. Corals provide physical structure to entire ecosystems, and are essential for defending coastlines against storms and tsunamis. Some invertebrates – such as anophiline mosquitos – are indeed dangerous pests, but we ignore them at our peril.

We tend to think of invertebrates as being small, and indeed most of them are. But there are some striking exceptions. Female giant squid can reach 18 m in length. On land, giant earthworms can reach at least 3 m. Giant clams can weigh more than 200 kg. Even among insects, there are some surprisingly large species. The giant weta in New Zealand can reach 70 g in weight. Big or small, there are some stunningly beautiful invertebrates. Butterflies of course come immediately to mind. But there some remarkable dragonflies, bees, velvet worms, nudibranch sea-slugs, cone shells, corals, starfish and many others. The diversity among invertebrates is extraordinary, and this is not surprising because in fact the term "invertebrate" is a convenience word to cover every species in all-but-one phyla of animals, plus those species in the phylum Chordata that do not have backbones. Put another way, vertebrates (the focus of so much conservation attention) are part of just one animal phylum, and invertebrates constitute all other animals!

Given the above facts, it is surprising that invertebrates receive relatively little conservation attention. The attention they receive in comparison to vertebrates is close to zero. Part of this is related to taxonomic problems. Many species are poorly known and hard to identify, and most have not even been discovered. In the IUCN Species Survival Commission we are now trying to expand the number of invertebrates species assessed for the IUCN Red List of Threatened Species. The early results of this work are included in this book. I very much hope that the expansion of conservation-related information on invertebrates will give invertebrates a much higher conservation profile in future.

I would like to thank our colleagues in the Zoological Society of London, especially Jonathan Baillie, Ben Collen and Monika Böhm for having had the vision to prepare this report and see it through to completion. And thanks are also due to the members of the invertebrate Specialist Groups and Red List Authorities of the IUCN Species Survival Commission, and staff of IUCN and Wildscreen, all of whom collaborated to produce this remarkable book. It is a fantastic achievement.



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General
The IUCN Red Listing process that underlies this report relies on the willingness of experts to contribute and pool their collective knowledge to make the most reliable estimates of the extinction risk of species. Without their enthusiastic commitment to species conservation, the overviews presented in this report would not be possible.

Many of the photographs that illustrate so beautifully the amazing diversity of forms of invertebrates were donated freely by enthusiastic photographers to ARKive. We thank them for bringing these species to life. We also thank George McGavin for some last minute species identification.

This report was funded by generous grants from The Rufford Foundation and the Esmée Fairbairn Foundation.

Chapter 2
The Freshwater Projects which provided the results used in this chapter would not have been possible without the many scientists involved in assessment, evaluation and compilation of the maps for each species. The IUCN Freshwater Biodiversity Unit, IUCN European Red List Project Staff and the Zoological Society of London Indicators & Assessments Unit provided support for the mapping and facilitation of workshops. The evaluation phase of the assessments has support from the IUCN Red List Unit.

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Chapter 3
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The main contributors to the cephalopod assessments have been Iain Barratt, Gillian Lyons, Mike Vecchione, Dick Young, Mandy Reid, Roger Villanueva and Martin Collins.

Chapter 4
This analysis is based on the data provided by numerous volunteers; in particular we wish to acknowledge the contributions to the butterfly and dung beetle sampled Red List assessments, and the European mollusc and saproxylic beetle assessments. We are grateful to Tom Brooks for facilitating use of NatureServe data.

Chapter 5
The European Red Lists were entirely dependent on hundreds of experts from all over Europe, who generously gave up their time and knowledge. Special thanks go to the Natural History Museum of Bern, Butterfly Conservation Europe and the European Invertebrate Survey, IUCN SSC specialist groups for molluscs and dragonflies, all of whom were key partners in the development of the molluscs, butterflies and dragonflies Red Lists.

We would like to thank the European Commission for providing the funds to develop the European Red Lists, which have enabled us to generate a comprehensive and detailed picture of biodiversity in Europe.

Chapter 6
We thank Jonathan Baillie for stimulating discussion, and Sven Vrdoljak for graphics work. MJS thanks the National Research Foundation, South Africa, for financial support. MB is supported by the Esmée Fairbairn Foundation.

Executive summary

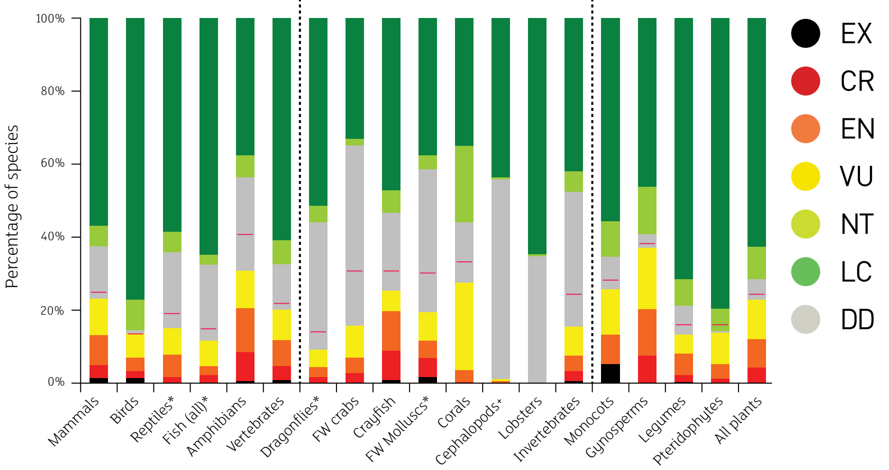
This report contains the most comprehensive assessment of the status and trends of the world's invertebrates conducted to date. It introduces the staggering diversity of invertebrates, ranging from microscopic zooplankton to giant squid. Together these organisms represent around 80% of the known species on our planet. They not only provide a bewilderingly rich and varied component of the natural world, they are our natural capital; the engineers of the many benefits which humans accrue from an intact and fully functioning environment. This report documents several reasons for concern about the health of invertebrates. The conservation attention paid to invertebrates to-date lags far behind that of vertebrates (mammals, birds, reptiles, amphibians and fish). If their path follows that of many of the high profile vertebrate species, our world would not only be depauperate in the organisms that give it life, but we would compromise the many benefits that humans gain from our environment.

This collaborative report brings together the work of many thousands of scientists through the IUCN Red List, to document how pressures on the environment are impacting invertebrates. Conservation assessments of the status of the 12,621 species of invertebrates assessed so far demonstrate the highest levels of threat to freshwater species, followed by their terrestrial and marine counterparts. This pattern is consistent with their backboned relatives, the vertebrates (Figure 01).

In much the same way as vertebrates, invertebrate extinction risk varies greatly across groups. To generalise, the highest risk of extinction tends to be associated with species that are less mobile and have small ranges. To make a vertebrate-invertebrate comparison, both amphibian and freshwater mollusc species share these traits, and face high threat levels (around one third of species threatened). In contrast, the global extinction risk experienced by flying insects such as dragonflies, damselflies, and butterflies tends to be much closer to that of birds (around one in ten species threatened).

It must be emphasized that while this is the most comprehensive assessment of invertebrate extinction risk to-date, the conservation status of less than 1% of all described invertebrates is known (Figure 02). Invertebrate assessment has lagged behind the vertebrates. One of the often cited reasons is a lack of information. Data are indeed often hard to come by, and are particularly poor for deep water marine invertebrates, and freshwater micro-invertebrates. However, this report demonstrates that a full understanding is possible, if a diverse range of approaches are employed. A number of iconic groups have been comprehensively assessed, including freshwater crabs, crayfish, lobsters, cuttlefish, reef-building corals, and additional comprehensive assessments of squid, octopuses, cone snails, reef-building oysters and sea cucumbers are nearing completion. Even groups that contain vast numbers, many tens of thousands of species, can be included in our measures of the changing state of nature, and are being understood using innovative methods for sampling. Insight into the conservation status of freshwater molluscs, butterflies, and dung beetles has been possible using such techniques.

Figure 01 | Global status of species on the Red List. The red bar shows the most likely percentage of threat assuming that species identified as Data Deficient (DD) show an equivalent proportion of threat as the species with sufficient information for an assessment.



Regional invertebrate assessments have also been carried out, often via national Red Listing. Groups have been assessed in great detail over larger areas, such as the invertebrate groups assessed as part of the pan-African freshwater assessment. The findings from this initial group of global, regional and national assessments provide important insight into the overall status of invertebrates. Together they indicate that the threat status of invertebrates is likely very similar to that of vertebrates and plants. If these findings prove to be representative across biodiversity as a whole, then one in five of all species on the planet may currently be threatened with extinction.

Identifying dominant threats to invertebrates should yield a focus for conservation activities. Findings vary by both major system (Chapter 2 – freshwater, Chapter 3 – marine and Chapter 4 - terrestrial) and by taxonomic group. Freshwater invertebrates are predominantly threatened by pollution such as nitrate and phosphate run-off from agricultural sources, followed by dam construction and off-take of water for irrigation of crops and domestic use. Terrestrial invertebrates appear to be equally threatened by agricultural expansion and intensification, and the negative consequences of invasive alien species. Marine invertebrates on the other hand are most susceptible to exploitation, human disturbance, and climate change. In addition to global warming, which is likely to become the dominant threat across all systems, the CO_2 absorbed by the oceans causes the water to become more acidic. The impacts that this will have on invertebrates in this century remain under investigation, but are potentially catastrophic.

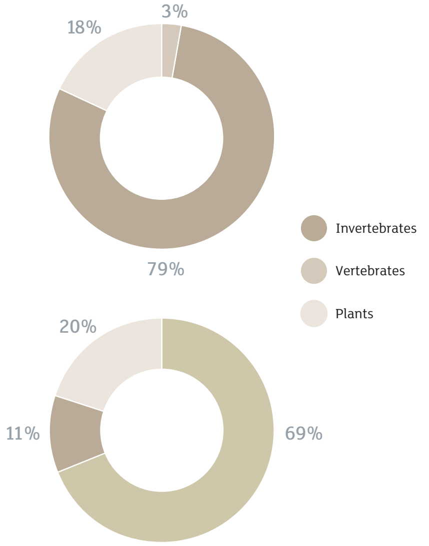
Recognising the growing pressures on invertebrates is important, as local declines lead to global extinctions. This loss is significant as each species is distinct, fascinating and beautiful, and part of the network of life that makes up our global ecosystem. There are additional more utilitarian reasons why we must stem the tide of invertebrate decline. Though their importance to human wellbeing is rarely recognised, invertebrates form the basis of many of the critical services that nature provides. For example, they help store carbon at the bottom of the ocean, filter water, decompose waste and recycle its nutrients, pollinate important crops, and are an essential part of the food web - ultimately feeding hundreds of millions of people. Simply put, if they disappeared tomorrow, we would soon follow. Not surprisingly, the value of the services provided by invertebrates is often estimated to be worth billions of dollars annually.

Ever-growing human demand for resources is putting tremendous pressures on invertebrates. To tackle these problems, there are two interlinked steps to take – we need to see the diversity of life in order to appreciate and value it, and we need to understand how it is changing in order to plan for the future. Focusing on invertebrates helps to truly illustrate the great diversity of the beautiful, fascinating and weird creatures with which we share the planet. It helps to put our place in the world into perspective, making it clear that we are only one tiny part of a global and interconnected complex web of life. It helps us to understand that we are more dependent on our spineless relatives than we ever imagined, and that it is truly the small things that make life possible.

From a moral and ethical perspective we must help ensure the future of the invertebrate creatures with which we share the world. From a selfish perspective, we must attempt to better understand the fundamental roles invertebrates play in critical ecosystems to ensure our own future security and wellbeing. It is not surprising our lives are so closely tied to invertebrates; we evolved from them and we have been dependant on them for millions of years. It would be both sad and imprudent to think we can live without them in the future.

If invertebrates disappeared tomorrow, humans would soon follow

Figure 02 | Proportion of major organismal taxa in nature (top) versus conservation literature (bottom)



Black-tailed Skimmer (*Orthetrum cancellatum*) © Mark Billiau

Green nettle weevil (*Phyllobius pomaceus*) © Nick Upton / naturepl.com

Hemipteran © George J. Reclos

1

The small things that run the world

Chapter 1
The unravelling underworld

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Introduction
As organisms get smaller, not only does our concern for them lessen, it is frequently the case that it moves from positive concern for their wellbeing, to negative concern about what ills they might inflict upon us. The human fascination with the larger and furrier organisms [e.g. 1] and our focussed conservation efforts towards the back-boned fauna of the world [2], results in the conservation neglect of some of the most interesting and beautiful creatures on the planet, and belies the critical underpinning role that invertebrates play in ecosystems, to the benefit of all humans.

Invertebrates are all around us and their diversity is one of the most striking aspects of our planet – on any one day we may be watching a butterfly fluttering past, picking up shells on the beach, digging up earthworms in our garden or evicting an unwelcome spider from the house. Invertebrates contribute a staggering 80% of species to the world's known biodiversity [e.g.3]. In measures of abundance and body mass, they are the dominant multi-cellular organisms, and together with plants and fungi provide us with the very foundations of life on our planet. The world famous biologist E.O. Wilson once claimed that "if human beings were to disappear tomorrow, the world would go on with little change" [4]. However, because of the importance of invertebrates as key players in the ecosystems on which humans rely for so much, the reverse is unlikely to be the case. Yet in many instances, we still lack sufficient information about the different roles invertebrates may play in our ecosystems, and what the interplay is between species diversity and ecosystem function. Given their importance to humans, why are invertebrates not monitored and protected to the same extent as their vertebrate counterparts? In this report, we set out to evaluate what is currently known about the status and trends of invertebrates in the oceans and along coastlines, and on the land, in terrestrial and freshwater ecosystems. We evaluate their importance to humans in providing a wide range of regulating, cultural and provisioning services in what is a complex and multilayered relationship between invertebrate diversity and ecosystem services [5].

With the vast majority of species still undescribed (Table 01: research suggests that between 65-80% of arthropods still await discovery and description [6-7]), humans lack much of the most fundamental information about this bewildering diversity of life. Even for those species which have been named and described, very little is known, even about fundamental properties, such as their distribution and basic ecology [8]. Over recent years, more and more studies have attempted to define and evaluate the contributions of species diversity to ecosystem services and functioning [e.g. 9]. As a result, there is a drive in certain conservation programmes to shift from a predominantly species-driven approach to a more ecosystems based approach. It is critical that species, the very organisms that underlie the complex workings of ecosystems, remain a focus of our research and conservation efforts, especially within integrated conservation programmes. In this chapter, we discuss the sheer diversity of invertebrates, evaluate their importance to ecosystems, the threats they face in the light of an ever-increasing human population, and the ways in which we can improve our collective knowledge on the conservation status of these "little things that run the world" [4] to achieve continuity of healthy ecosystems into the future.

Table 01 | Described and estimated species richness of invertebrates and vertebrates [Scheffers *et al.* (2012)]

Phylum	Within phylum	Currently catalogued	Estimated species
Porifera		6,000	18,000
Cnidaria		9,795	N/A
Mollusca		85,000	200,000
Annelida		16,763	30,000
Arthropoda	Arachnida	102,248	600,000
	Myriapoda	16,072	90,000
	Insecta	1,000,000	5,000,000
	Crustacea	47,000	150,000
Platyhelminthes		25,000	500,000
Nematoda		7,003	14,000
Echinodermata		12,673	20,000
Other invertebrates		64,788	80,500
Total invertebrates		1,392,342	6,702,500
Chordata	Mammals	5,487	5,500
	Birds	9,990	10,000
	Reptiles	8,734	10,000
	Amphibians	6,515	15,000
	Fishes	31,269	40,000
Total vertebrates		61,995	80,500

Rhinocerus beetle (*Chalcosoma moellenkampi*)
© Trond Larsen

Red-veined Darter (*Sympetrum fonscolombii*) © George J. Reclos

Invertebrate diversity

The Cambrian explosion, some 530 million years ago, marked a time at which an astonishing diversity of invertebrates, including all of the major modern phyla, became apparent in the fossil record. How and why this event took place is still a matter of debate among palaeontologists and evolutionary biologists, and while it may even be that complex animal life had evolved earlier during the Precambrian, it is undoubtedly a time when an astounding variety of invertebrate body plans became apparent [10-11]. Some sponge spicules (structural elements found in most sponges) have been dated back to 580 million years before present, and it has been suggested by some researchers that the Ediacaran fauna (550-600 million years ago) contained representatives of modern invertebrate groups [12-13]. It is hardly surprising that over the course of this long evolutionary history, invertebrates have established themselves in a staggering array of forms and sizes, dominating terrestrial, freshwater and marine ecosystems alike.

Today, invertebrates comprise of a wide spectrum of animal life forms, from simple sponges and jellyfish to the ancestors of vertebrate life in the phylum Chordata. While insects are by far the most numerous group of invertebrates with at least 1 million species (and probably many more), there are also more than 100,000 described arachnids (spiders, scorpions, ticks, mites, etc), around 85,000 species of molluscs (clams, mussels, snails, slugs, octopi, etc), and in excess of 45,000 species of crustaceans (lobsters, crabs, barnacles etc), amongst others. Given these numbers, it is hardly surprising that overall, our knowledge of invertebrate conservation status and trends is limited. However, from what we know, there are some troubling signs. The following is a brief introduction to the bewildering and often stunning diversity of invertebrates and highlights some of the key players in terrestrial, freshwater and marine systems.

Sponges

The exclusively aquatic sponges (phylum Porifera) are considered the most basic of metazoan animals, and are particularly associated with corals reefs, mangroves and sea grass ecosystems. Sponges can form sponge gardens, which are often highly species rich [14] and provide nursery grounds for fish [15]. Sponges generally filter feed on bacteria and other food particles in the water, although some species have become carnivorous, preying on small crustaceans.

Corals, jellyfish and anemones

Members of the phyla Ctenophora and Cnidaria include sea anemones, corals and jellyfish. Corals are tiny organisms which live in colonies and are responsible for providing the physical structure of coral reefs. These reefs harbour an enormous diversity and concentration of species and as a result are often referred to as the marine equivalent to terrestrial rainforests. Worldwide, around 500 million people are dependent on the resources coral reefs supply, such as protein from fish and crustaceans, income from fishing, coastal protection and tourism [16]. Since 1990, more than 75% of all new marine natural products from invertebrates (e.g., therapeutic compounds, innovative biotechnology products) have been derived from members of the sponges and Cnidaria [17], so that these phyla have played a central role in recent bioprospecting endeavours.

Worms

The animals that are often colloquially referred to as 'worms' are in fact a highly diverse range of organisms representing three different phyla. There are flatworms (phylum Platyhelminthes, some of the best known members of which are parasites of humans and livestock, e.g., tapeworms and liver flukes), roundworms (phylum Nematoda, with a major claim to fame that one of its members, *Caenorhabditis elegans*, was the first multicellular organism to have its genome completely sequenced [18]), and ringed worms (phylum Annelida, earthworms and leeches are the best known members of this phylum). These phyla are highly species rich. While at present just under 50,000 species have been described, some authors estimate the true number of species within these phyla to be between half a million to one million species (see Table 01; [19]).

Hemipteran © Madjid Momeni Moghaddam

Grasshopper (Acrididae) © Madjid Momeni Moghaddam

Molluscs

Mollusca is the most numerous phylum of marine invertebrates; molluscs are also widely

Jumping spider (*Habronattus hirsutus*) © Lisa Taylor

Invertebrates contribute a staggering 80% of species to the world's known biodiversity

present in terrestrial and freshwater systems. This group is second only to the Arthropoda in overall diversity [20], with over 80,000 species described [21]. It encompasses a large number of different forms, from giant squids growing to more than 10 m in length to micromolluscs of less than 1 mm in size. Several species are long lived, for example the freshwater pearl mussel *Margaritifera margaritifera* has been estimated to reach ages of up to 190 years [22], and the oldest clam ever found was thought to be around 400 years old.

Insects, arachnids and crustaceans

Arthropods are by far the most species-rich phylum of invertebrates. They can be distinguished from other, lower invertebrates by their segmented body plan as well as more complex features such as an exoskeleton and jointed legs. Estimates of the number of arthropod species on our planet range from more than one million described species to between five and 10 million extant species [23] – and has been estimated as high as 30 million [24], although this number has been much debated [3,7,25]. Arthropoda is comprised of the subphyla Chelicerata (spiders and horseshoe crabs), Myriapoda (millipedes and centipedes), Crustacea (lobsters, crabs, shrimp, etc) and the most numerous of them all, the Hexapoda (insects). Of the insects, the beetles are by far the most species-rich group, comprising around 40% of all described insects [24]. Having taken to the air long before birds and even pterodactyls, insects have been particularly successful at colonising a large number of habitats across the world, and are key players in providing humans with vital services from the natural world, including pollination, decomposition and natural pest control. Amongst marine crustaceans, the Antarctic krill *Euphausia superba* represents probably the most abundant species worldwide in terms of biomass, and plays a crucial role in the food chain as the main prey for a wide variety of predators thus sustaining the diversity of marine vertebrates within the system, including megafauna such as whales, as well as seals penguins and fish.

Echinoderms

Sea urchins, starfish, brittle stars, feather stars and sea cucumbers belong to the phylum Echinodermata. Echinoderms are taken in commercial fisheries, aquarium and souvenir trades, bioprospecting for bioactive compounds, and for experimental models in studies on evolution and toxicology [26]. Many members of this group play important roles in the ecology of marine systems. For example, the purple sea urchin (*Strongylocentrotus purpuratus*) is an extensive grazer of kelp forests, helping to alternate its environment between two states – species-rich kelp forests and sea urchin-dominated barren areas [27].

Our closest invertebrate relations

Humans and all other vertebrates belong to the phylum Chordata, where they are classed in the subphylum Vertebrata. Tunicates and lancelets make up the other two subphyla of Chordata, and are thus our closest invertebrate relations. The lancelets (also known as amphioxus) are small, fish-like marine creatures, and are best known for the central role they have played in studying the evolution of vertebrates, providing the most basal view of chordate evolution [28,29]. Although on first sight both tunicates and lancelets show very basic body plans compared to the vertebrates, they share a structure called the notochord with embryonic vertebrates.

Diverse forms, diverse functions

Many other phyla complete the highly diverse portrait of the invertebrates, such

Swallowtail butterfly (*Papilio machaon*) © Marco Bertolini

Paramastax poecilosoma © Carolina Holguin

Shield bugs © George J. Reclos

Male yellow dung fly (*Scathophaga stercoraria*)
© Nick Upton / naturepl.com

as the mostly tropical velvet worms, which prey on other invertebrates by squirting and entrapping their prey with an adhesive slime, and the two species-strong phylum Xenoturbellida, simple worms which have recently been shown to belong to the deuterostomes, a group which also includes the vertebrates [30].

Foundations of biodiversity – why invertebrates matter

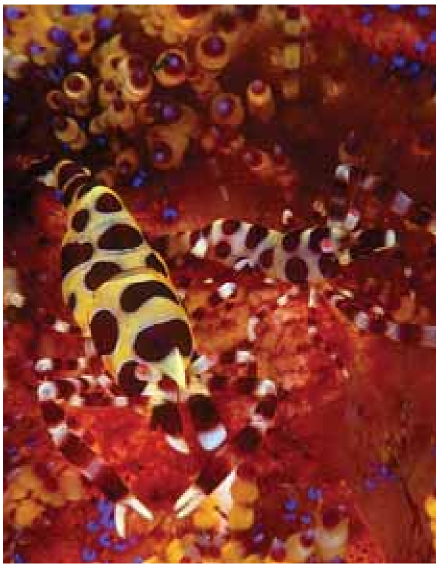
With such enormous levels of diversity and unique traits, it is not surprising that invertebrates on many occasions have become embedded within human culture. For example, *Scarabaeus sacer*, a dung-rolling member of the dung beetle family Scarabaeidae, was sacred to the ancient Egyptians, seen as a symbol of the sun god Khepri rolling the sun across the sky. The praying mantis is revered by the Khoi in Southern African indigenous mythology as a manifestation of the god Cagn. Throughout history, humans have been particularly captivated by the colourful components of the invertebrate world such as corals, butterflies or dragonflies, but the relative profile of invertebrates in human culture remains low, given they represent the majority of life on earth. However, they appear to be slowly gaining ground as their fascinating life histories, behaviour and ecology are better understood and communicated using technology that enables the public to experience the wonder of the invertebrate world up close.

However, there is an additional and more utilitarian argument for why invertebrates matter to humans. Invertebrates are the very foundation of the ecosystems that supply humans with many essential services, and are therefore important to our day-to-day lives. In some cases, these services are immediately apparent, such as for bees, where honey production and pollination services are the immediate outcome of benefit to humans. Gardeners appreciate the contribution of earthworms and other soil invertebrates to the provisioning of aerated and fertile soils for horticulture. Other services are probably less obvious, but are nonetheless equally critical. For example, macroinvertebrates in freshwater systems play a significant role in the decomposition of plant and other waste material, just like their terrestrial counterparts, but the resulting benefit of clean and healthy freshwater systems is much less tangible than some of the more obvious ecosystem services invertebrates provide. In many cases, little is realised about the contribution these species make to our daily lives. Invertebrates play key roles at all levels of the ecosystem service hierarchy: as a regulator of underpinning ecosystem processes, as a final ecosystem service and as a good that is subject to valuation, whether economic or otherwise, forming an integral part of our natural capital.

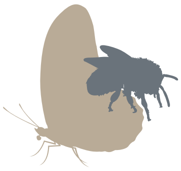
Invertebrates are intricately inter-linked both with other invertebrate species and with plants, fungi and vertebrates, via many ecological interactions. Insects such as bees, butterflies and moths pollinate plants, marine planktonic invertebrates such as krill support complex food webs, and corals provide structural habitat for an astonishing diversity and abundance of species. In recent years, an increased focus has been placed on understanding the way in which the diversity of species on earth and the abundance of those species provide humans with ecosystem services [e.g. 5,31-32]. Although many studies have shown a reduction in ecosystem function with a decrease in biodiversity [e.g. see 33], there is still great uncertainty about the precise relationship between these two complex measures. For example, it is often difficult to evaluate the relative contribution of different species groups to a given service that is provided, and how the rate and pattern of species loss is impacting the provision of that service, and the function of the ecosystem.

One of the most critical questions which scientists must answer is which species are essential for the provisioning of critical ecosystem services? This will determine the extent to which using the ecosystem service argument alone is effective for promoting biodiversity conservation. Regardless of the outcome, it is clear the invertebrates play a much more important role in the provisioning of essential ecosystem services than vertebrates.

In the Millennium Ecosystem Assessment [31], services that humans derived from ecosystems were classified into four categories: provisioning, regulating, cultural and supporting services. The overlaps and interdependence of these categories, and the underpinning role of supporting services, have led to several refinements. Here, we use a framework which has stemmed from the UK National Ecosystem Assessment [34], devised by Mace *et al*. [5], to define ecosystem services provided by invertebrates.



Left: Hoverfly (*Syrphidae* sp.) © Trond Larsen
Right: Coleman shrimp pair on fire urchin (*Periclimenes colemani* on *Asthenosoma varium*) © Christopher J. Crowley



$3 Billion - Value of insect pollinators in the US alone between 2001-03

Invertebrate diversity as a regulator of ecosystem processes
Insects provide the basis to many ecological processes which humans depend on, such as decomposition, nutrient cycling, pest control, and pollination ensuring the stability of non-agricultural systems [35]. For example, dung beetles are very effective at decomposing waste from both wildlife and farmed livestock. This helps to enhance forage palatability, recycle nitrogen into the system, and reduce pest habitat. As a result, total economic losses averted by the U.S. cattle industry by the presence of dung beetles have been estimated at $0.38 billion [36].

In marine systems, coral reefs provide a multitude of regulatory services. Amongst those are shoreline protection, nitrogen fixation and the capacity to act as a sink for carbon dioxide [37]. Further, they provide key habitat for both commercially important and subsistence fisheries. For example, the estimated economic value of healthy reefs towards fisheries production in the Caribbean has been estimated in excess of $300 million for the year 2000, while degradation of reefs could lead to a loss of around $100 million to fisheries by 2015 [38].

Invertebrates hold many more vital roles in our ecosystems. For example, mussels provide filtration of the water column and deposition of filtered organic matter within the sediment thus linking benthic and pelagic systems via nutrient transferral from one to the other [39]; groundwater invertebrates may play significant parts in biogeochemical cycling of nutrients and carbon, though this requires further study of this poorly known fauna [40-41]. The demise of invertebrate species can therefore often act as an indicator of failing habitats, ecosystems and regulatory services to humans.

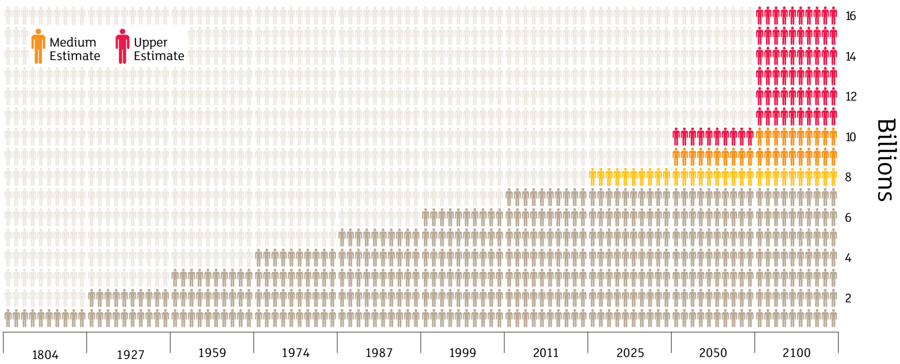
Invertebrate diversity as a final ecosystem service
Invertebrates contribute directly to some goods, such as food and pharmaceuticals. For example, invertebrates of terrestrial, freshwater and marine systems provide vital protein sources to millions of people worldwide (e.g. marine invertebrates, [42]; freshwater molluscs, [43]; insects, [44]). Insect pollinators provide the security of many food crops. Pollination services provide humans with vital food sources such as field crops, fruits, nuts, and vegetables, and have been estimated in the USA alone at a value of around $3 billion between 2001 and 2003 [36] and $14.6 billion in 2000 [45]. Similarly, empirical evidence exists where pollinator scarcity or low pollination activity have resulted in crop yield declines or failures [46-47]. Organisms with secondary compounds with the potential for commercial exploitation, for example novel pharmaceuticals, are further examples of where invertebrates are fundamental in provisioning a final ecosystem service.

Invertebrate diversity as a good
Invertebrates themselves, like other components of biodiversity, are valued by humans for their cultural, spiritual or recreational value. Apart from their multiple regulatory services, coral reefs have a high recreational value, by providing diving and wildlife viewing opportunities, curios, ornamental fish for the aquatics trade, and in turn provide an important source of local income [37]. Studies have suggested that dive tourism in the Caribbean alone brought in US$ 2 billion in 2000 [see 38], while the global recreational value of reefs has been valued at approximately US$ 3,000 per hectare per year [48]. Other invertebrates have become popular tourist attractions, thus providing value to national economies. In the same way in which the annual migration of a million wildebeest is a major tourist attraction to parks like Serengeti National Park, the return of millions of monarch butterflies to their overwintering grounds in Mexico has attracted tourists from around the world. Key areas are protected and can be visited within the Monarch Butterfly Biosphere Reserve, which has been designated as a UNESCO World Heritage Site, again underpinning the value of this natural spectacle to humanity. Below ground, the luminescence of thousands of larvae of the glow worm *Arachnocampa luminosa* attracts busloads of tourists to show caves in New Zealand.

Common blue butterfly (*Polyommatus icarus*) © Nick Upton / naturepl.com

Polymita picta roseolimbata © Adrián González-Guillén

Figure 01 | Human population growth and projections from UNFPA.



Restricted-range species tied to particular habitats are at greater risk in all systems in comparison to wide-ranging species with more generalist ecological requirements. While some of the major threatening processes differ between taxa (e.g., broadly speaking, over-exploitation is less of a threat for Odonata and crabs than for terrestrial vertebrates, particularly mammals), habitat loss and degradation represent major threats across all groups.

In situations where habitat loss is the primary cause of decline (Figure 03), it is reasonable to assume that there might be a positive correlation between declines in vertebrate and non-vertebrate populations.

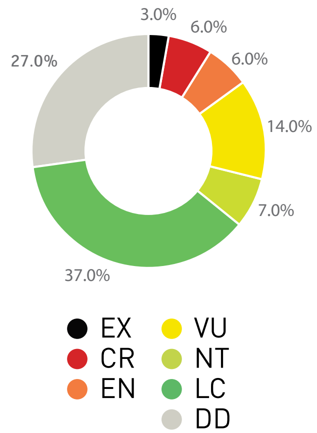
Invertebrates under threat

The human population reached an estimated 7 billion people in late 2011 (Figure 01: [49]). Reaching this milestone indicates that pressure on our ecosystems and the species we share this planet with is ever-increasing. Going hand-in-hand with human population increase, a staggering 30% overall decline in vertebrate populations has been reported since 1970 [50]. While no similar global measure exists at present for invertebrates, there are some worrying signs. Population declines are a prelude to species extinction [51-52], and there are ample indications of population declines and potential for high extinction risk in many groups of invertebrates. Pollinator declines in particular have made the news in the past years, because of the obvious effects on ecosystem stability, crop production and food security. Over recent years, evidence has been mounting to suggest global declines in pollinators [53]. Bumblebees have been particularly well studied and declines have been observed throughout North America, Europe and Asia, often caused by changing agricultural policies and land use [54]. Also, despite relatively few documented invertebrate extinctions, it has been suggested that extinction and threat in understudied taxa such as invertebrates has been severely underestimated, by as much as three orders of magnitude [e.g., 55].

However, population declines, threat levels and extinction rates are not uniformly distributed across species and space. For example, vertebrate population declines have been far greater in tropical and freshwater systems [50,56] and amphibians show much higher threat levels than other vertebrate groups, with more than 40% of species at risk of extinction [57-58]. So far, most of what is known about species declines comes from vertebrate research. However, vertebrates represent just 4.6% of the world's animal species, while invertebrates contribute the vast majority of species towards animal biodiversity [59]. So the question really is, how well do threat levels reported in vertebrates represent what is happening in invertebrates and to what extent do anthropogenic threats causing wide-spread decline in vertebrates affect the invertebrate species that run our ecosystems [60]?

As will become apparent in the coming chapters, evidence is mixed. On the whole, rather than differences between vertebrates and invertebrates *per se*, the assessments highlighted in the following chapters suggest that key differences exist between system and habitat, regardless of whether the species is a vertebrate or not (Figure 02). Freshwater groups [61] are consistently at higher risk than their terrestrial counterparts [62], yet it is a system about which we still know very little.

Figure 02 | Global status of invertebrates currently assessed on the IUCN Red List (12,621 species)



However, where threats such as exploitation or pollution are the cause of a decline, the expectation might be that trends observed in one set of species will not necessarily be indicative of population trends in other species in the same ecosystem. The impacts of climate change remain complex, though an increased understanding of species biology may provide some clues [e.g. 63]. Addressing the lack of invertebrate coverage on the IUCN Red List to date, as will become apparent in the following chapters, is particularly pressing in view of

Freshwater species are consistently at higher risk than their terrestrial counterparts

Digger bee (*Amegilla* sp.)© Madjid Momeni Moghaddam

Dung beetle (*Anoplotrupes stercorosus*) © Mark Billiau

Hooded praying mantis © Trond Larsen

the ecosystem services that they provide; therefore, it is important that they be assessed, inventoried, monitored, and protected [64].

Our planet's ecosystems have changed more rapidly in the second half of the twentieth century than at any time in human history [31]. For example, in terrestrial systems, there has been an increase in the rate of conversion of land to cropland; freshwater ecosystems have been increasingly degraded by the duel impacts of damming and water extraction; and coral reefs, by far the most diverse marine habitat, have undergone severe degradation over the past decades through coral bleaching. With these significant changes to our natural world, it would be naive to assume that the number of extant species and the abundance of invertebrates have continued to exist unchanged. Despite the general lack or paucity of data on invertebrates, decline rates matching or even exceeding those observed in vertebrates have been suggested from past research [55,65].

Invertebrates and policy

At the Rio Earth Summit in 1992, the Convention on Biological Diversity (CBD) was signed by 150 governments, recognising that sustainable development is essential in order to sustain the biological diversity of life and the many important services it provides to humans. Since 1992, many more countries have signed the convention, which is now ratified by 193 parties. The main goals of the convention are to conserve the world's biodiversity, to sustainably use components of biodiversity and share equitably the benefits arising from the use of genetic resources [66]. Invertebrates supply the bulk of the planet's species diversity, which is also referred to as biodiversity and which is defined by the CBD as "the variability among living organisms from all sources including, ..., terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part" [66]. It is therefore apparent that signatories to the CBD have signed up to the conservation of invertebrates as well as the ecological functions they provide. At a global level, the CBD 2010 target, which aimed to achieve a significant reduction in the rate of biodiversity loss, was not achieved [67-68]. At regional levels, similar targets were set. For example, in Europe, the 2001 EU Strategy for Sustainable Development included a target to halt biodiversity decline by 2010, but this was again not achieved [69-70]. In moving to a set of 20 new and refined targets, the Aichi Targets (see Box 01), those signatory parties have committed to invertebrate conservation in a framework to be translated into national biodiversity strategies and action plans by 2014 [71].

Figure 03 | Global threat to all invertebrates on the IUCN Red List horizontal axis shows the proportion of threatened (CR, EN, VU) species affected by each of the threatening processes on the vertical axis. Note - these numbers may add up to more than 1 because species are often affected by multiple threats

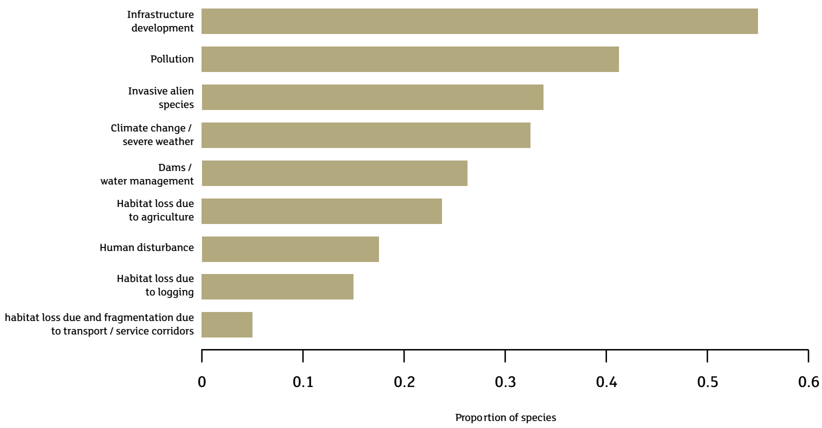
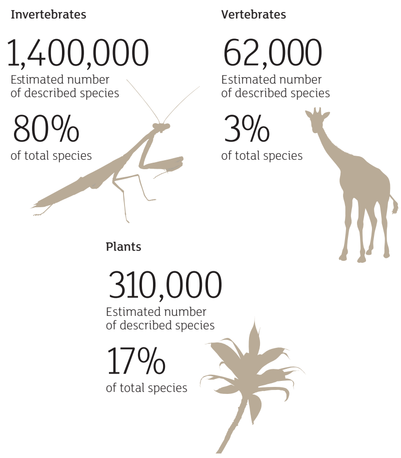


Figure 04 | Estimated number of described species and the percentage of total species they represent [based on Scheffers *et al.* (2012)].



Box 01 | The 2020 Aichi Biodiversity Targets

Strategic goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society

Target 1 By 2020, at the latest, people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably

Target 2 By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.

Target 3 By 2020, at the latest, incentives, including subsidies, harmful to biodiversity are eliminated, phased out or reformed in order to minimize or avoid negative impacts, and positive incentives for the conservation and sustainable use of biodiversity are developed and applied, consistent and in harmony with the Convention and other relevant international obligations, taking into account national socio economic conditions.

Target 4 By 2020, at the latest, Governments, business and stakeholders at all levels have taken steps to achieve or have implemented plans for sustainable production and consumption and have kept the impacts of use of natural resources well within safe ecological limits.

Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use

Target 5 By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced.

Target 6 By 2020 all fish and invertebrate stocks and aquatic plants are managed and harvested sustainably, legally and applying ecosystem based approaches, so that overfishing is avoided, recovery plans and measures are in place for all depleted species, fisheries have no significant adverse impacts on threatened species and vulnerable ecosystems and the impacts of fisheries on stocks, species and ecosystems are within safe ecological limits.

Target 7 By 2020 areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity.

Target 8 By 2020, pollution, including from excess nutrients, has been brought to levels that are not detrimental to ecosystem function and biodiversity.

Target 9 By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment.

Target 10 By 2015, the multiple anthropogenic pressures on coral reefs, and other vulnerable ecosystems impacted by climate change or ocean acidification are minimized, so as to maintain their integrity and functioning.

Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity

Target 11 By 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes.

Target 12 By 2020 the extinction of known threatened species has been prevented and their conservation status, particularly of those most in decline, has been improved and sustained.

Target 13 By 2020, the genetic diversity of cultivated plants and farmed and domesticated animals and of wild relatives, including other socio-economically as well as culturally valuable species, is maintained, and strategies have been developed and implemented for minimizing genetic erosion and safeguarding their genetic diversity.

Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services

Target 14 By 2020, ecosystems that provide essential services, including services related to water, and contribute to health, livelihoods and well-being, are restored and safeguarded, taking into account the needs of women, indigenous and local communities, and the poor and vulnerable.

Target 15 By 2020, ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced, through conservation and restoration, including restoration of at least 15 per cent of degraded ecosystems, thereby contributing to climate change mitigation and adaptation and to combating desertification.

Target 16 By 2015, the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization is in force and operational, consistent with national legislation.

Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building

Target 17 By 2015 each Party has developed, adopted as a policy instrument, and has commenced implementing an effective, participatory and updated national biodiversity strategy and action plan.

Target 18 By 2020, the traditional knowledge, innovations and practices of indigenous and local communities relevant for the conservation and sustainable use of biodiversity, and their customary use of biological resources, are respected, subject to national legislation and relevant international obligations, and fully integrated and reflected in the implementation of the Convention with the full and effective participation of indigenous and local communities, at all relevant levels.

Target 19 By 2020, knowledge, the science base and technologies relating to biodiversity, its values, functioning, status and trends, and the consequences of its loss, are improved, widely shared and transferred, and applied.

Target 20 By 2020, at the latest, the mobilization of financial resources for effectively implementing the Strategic Plan for Biodiversity 2011-2020 from all sources, and in accordance with the consolidated and agreed process in the Strategy for Resource Mobilization, should increase substantially from the current levels. This target will be subject to changes contingent to resource needs assessments to be developed and reported by Parties.

Scorpion © Trond Larsen

Box 02 | Tracking the status of invertebrates
The realisation that invertebrate conservation has previously been widely overlooked has led to the establishment of specialist networks and a variety of projects which aim at increasing our knowledge on the status and trends of invertebrates. Specifically, a multi-faceted approach has been set up within the remit of the IUCN Red List partnership.

The IUCN Invertebrate Conservation Sub-committee was established in 2005 to tackle this enormous challenge, and its membership comprises of representatives of the respective invertebrate specialist groups within the IUCN Species Survival Commission.

Beyond this taxon-oriented approach, specific programmes are involved in invertebrate species assessments within IUCN. Using a regional approach, the IUCN Freshwater Biodiversity Unit is carrying out comprehensive Red List assessments for key groups of freshwater species, amongst those the dragonflies and molluscs, in order to identify critical sites for the conservation of these species groups and freshwaters as a whole. For example, a comprehensive pan-African assessment has been carried out in collaboration with several partner organisations, assessing the status of freshwater fishes, molluscs, crabs, dragonflies and a selection of freshwater plants across continental Africa [74]. Other recent initiatives have focussed on the Eastern Himalayan region and Indo-Burma. Chapter two highlights the latest from these and other related projects.

The IUCN Marine Biodiversity Unit is conducting the Global Marine Species Assessment, the first global review of the threat of extinction for every marine vertebrate species, plants and selected invertebrates. As a result, the unit has been compiling Red List assessments for marine invertebrates (e.g. reef-building corals, [75]) and supporting marine assessment initiatives spearheaded by other organisations (e.g. cone snails). In chapter three, we highlight the latest findings from these and other related projects.

With the current extinction crisis, it is vital that representative information on trends in species' extinction risk is obtained in a timely manner. Since complete assessments of many of the highly species-rich invertebrate groups would be prohibitively time-consuming and costly, shortcuts are urgently required on current threats, trends and actions needed across terrestrial, freshwater and marine environments [76]. A sampled approach to Red Listing [77] provides one such short-cut, by assessing extinction risk across a number of species groups, each of which is represented by a randomly selected representative subset of 1,500 species. Freshwater molluscs, dragonflies, dung beetles and butterflies were selected to represent invertebrates in this way, and this was supplemented by comprehensive assessments of crayfish, freshwater crabs, reef-building corals and cephalopods [60]. Throughout this report, we report findings from the project, specifically in Chapters two, three and four.

Regional and National Red Lists are important tools to guide conservation priorities and track progress towards biodiversity targets at the level of policy implementation. At present, invertebrates are still among the most poorly represented taxonomic groups in National Red Lists, together with fungi and lichens, with the best coverage of species in Europe and North America [78]. In one example, an assessment project is currently ongoing for Europe, which to date has assessed freshwater and terrestrial molluscs [79], butterflies [80], dragonflies [81] and saproxylic beetles [82]. In Chapter five, we review how well national-level assessments and action plans incorporate invertebrate biological data, and how such information might be used for deriving the value of natural capital and steer policy decision-making.

Other international biodiversity conventions cover selected species which are listed within their appendices. The Convention on Migratory Species (CMS), not surprisingly, only includes a single invertebrate representative, the Monarch butterfly *Danaus plexippus*. A wider range of invertebrates, including species of sea cucumber, tarantula, scorpion, beetle, butterfly, medicinal leech, freshwater and marine mussel, clam, snail and coral, are included to varying degrees on the three appendices of the Convention on the International Trade in Endangered Species of Wild Fauna and Flora (CITES). Overall, however, it has often been observed that invertebrates remain overlooked politically in favour of more charismatic species – the 'political dilemma' [72]. However, as part of signatories' commitments to international agreements such as the Convention on Biological Diversity, countries and regions have started to identify priority species for conservation and to monitor the status of these species. Again, invertebrate coverage is lagging behind that of vertebrate species within these initiatives [e.g., 73]. However, the European Habitat Directive, the main legislative work for European nature conservation, currently includes around 150 invertebrates (arthropods and molluscs).

Conclusions

Invertebrates are a diverse and vital part of our functioning natural Earth (Figure 04). In this report, we set out to evaluate what is currently known about the status and trends of invertebrates in the oceans and along coastlines, and on the land, in terrestrial and freshwater ecosystems. We move on to evaluate their importance to humans in providing a wide range of regulating, cultural and provisioning services in what is a complex and multilayered relationship between invertebrate diversity and ecosystem services, and set out a vision for how they can be effectively monitored, and how invertebrate conservation can succeed in the coming decades.

Stick Grasshopper (*Paraproscopia riedei*)
© Christopher J. Crowley

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Drymaeus sp. © Adrián González-Guillén

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German wasp (*Vespula germanica*) © George J. Reclos

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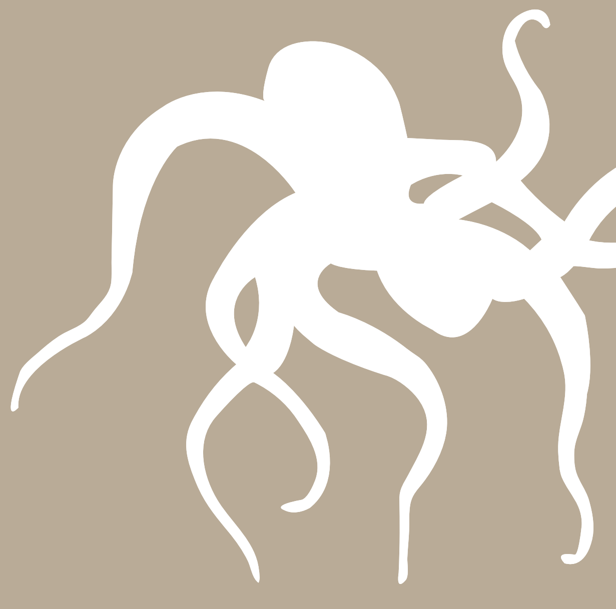
Status and trends of invertebrates



Chapter 2
Freshwater invertebrate life

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Introduction
Freshwater ecosystems are considered to be in decline, suffering from a large degree of exploitation and pollution and a resulting deterioration in water quality [1]. There have been various attempts to document their status over the last few years evaluating extinction risk in certain regions and groups of invertebrates [2] and population decline in vertebrate fauna [3-4]. Vörösmarty *et al.* [5] noted the worldwide pattern of threats to rivers, and offered the most comprehensive explanation so far of why freshwater biodiversity is considered to be in a state of crisis. Vörösmarty *et al.* [5] estimated that at least 10,000–20,000 freshwater species are either already extinct or at risk of extinction, which could equate to between 10-15% of known species. These threat levels directly affect humans. Eighty percent of the global human population are exposed to high levels of threat to water security [5]. This figure is higher for those humans at a low income level (Figure 01). High risk areas for humans are highly coincident with the prevailing areas of high risk to invertebrate diversity. Their analysis was based on the state of river systems, rather than an analysis of the threats to individual species. The data presented here provides a first overview of the status of freshwater invertebrate fauna, based on a species data set assessing the threats to 7,784 freshwater invertebrates, *c.* 10% of all known freshwater invertebrate species.

Large-scale biodiversity assessments have frequently focused on a limited range of taxonomic groups, most often including those groups that provide obvious benefits to humans through direct consumption, or the more charismatic groups, such as mammals and birds. In the case of aquatic systems, it is the wetland birds and fishes that have received most attention. Given widely differing levels of available knowledge for the range of invertebrate groups, combined with their large numbers, it has so far only been possible to assess the status and map the distributions of species for a relatively small number of taxonomic groups. Here we report on the results so far obtained for freshwater crabs, crayfishes, molluscs and dragonflies and damselflies (Odonata).

Diversity of the system
The majority of the estimated 126,000 freshwater animals are invertebrates, comprising mainly insects (60%) and crustaceans (10%) [6]. Freshwater invertebrates are vital components of the food web and essential to the maintenance of healthy functioning wetland ecosystems, even if they are often neither charismatic nor noticed by humans. Molluscs, crustaceans, and Odonata are the groups which have the best documented extinction risk assessments [7].

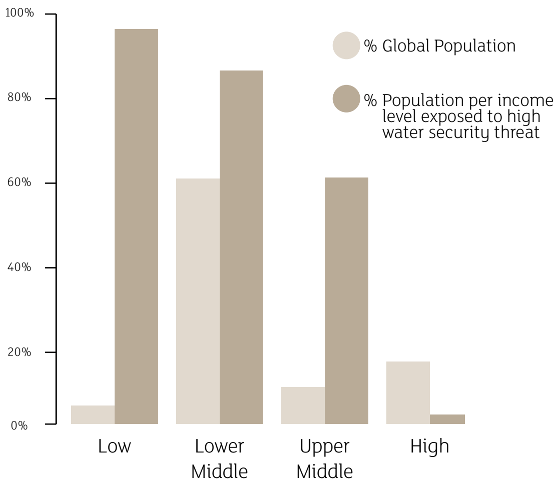
Freshwater molluscs are one of the most diverse and threatened groups of animals [8-10]. They are mostly unobtrusive, and are not normally considered to be charismatic creatures; they rarely attract the attention of the popular media. They have been portrayed on some occasions in a negative light, as some species play a significant role (as a vector) in the transmission of human and livestock parasites and diseases. This is unfortunate, as freshwater molluscs play a key role in the provision of ecosystem services and are essential to the maintenance of wetlands, primarily due to their contribution to water quality and nutrient cycling through filter-feeding, algal-grazing and as a food source to other animals [see 8,11-13]. Some species are of high commercial importance to humans as food or ornaments (e.g. clams, and some mussels and snails). There are just fewer than 5,000 freshwater mollusc species [14-15] for which valid descriptions exist, in addition to a possible 4,000 undescribed gastropod species [15].

Larvae of almost all species of dragonflies and damselflies are dependent on freshwater habitats. The habitat selection of adult dragonflies strongly depends on the terrestrial vegetation type, and their larvae develop in water where they play a critical role in determining water quality, aiding nutrient cycling, and developing aquatic habitat structure. The larvae are voracious predators, often regarded as important in the control of insect pest species. A full array of ecological niches is represented within the group and, as they are susceptible to changes in water flow, turbidity or loss of aquatic vegetation [16], they have been widely used as an indicator for wetland quality [17]. There are 5,680 extant described species of dragonfly and damselfly. However, even though the group is well studied, it is believed that the actual number is close to 7,000 species [18]. With the exception of Antarctica, dragonflies and damselflies are widespread and abundant on all continents, although centres of species richness typically occur in tropical forests clustered in the Neotropical and Indo-Malayan realms, which contain almost 60% of the world's diversity of this taxon [19].

There are 1,280 species of freshwater crabs [20], together representing one of the most ecologically important macro-invertebrate groups in tropical inland waters worldwide

Dragonfly (just emerged) © James Reardon.org

Figure 01 | Eighty percent of the global human population are exposed to high levels of threat to water security. Data from [5].



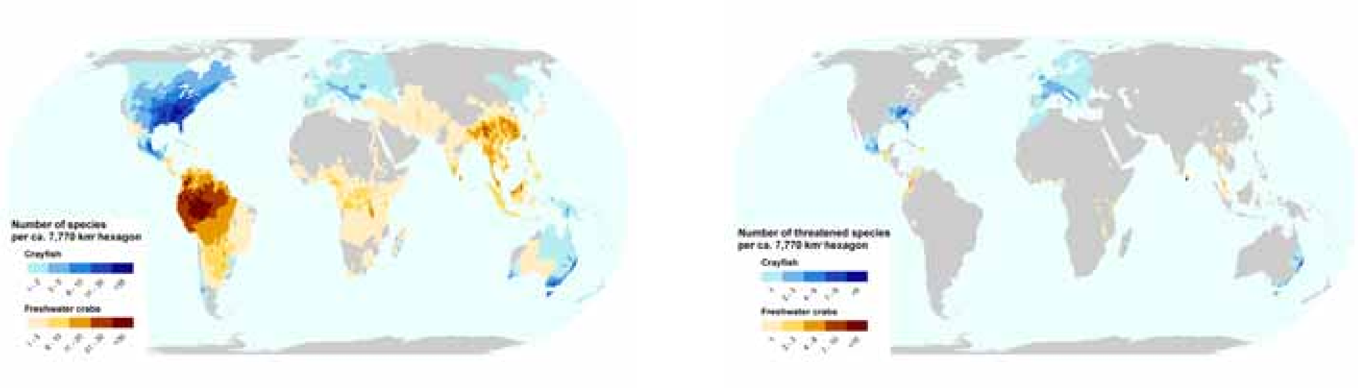


Figure 02 | Global species richness and threatened species richness of crabs and crayfish. Species distribution maps showing overall species richness (left) and threatened species richness (right) of crayfish (blue shades) and freshwater crabs (red shades). Data from complete global assessments of crayfish (n = 590) and freshwater crabs (n = 1,281).

[21-26]. These strictly freshwater decapods are found in almost all clean freshwater bodies in the tropics from moist lowland forests to rugged mountains. Almost all require pristine water conditions to survive and are excellent indicators of good water quality [26]. Freshwater crabs provide an important nutrient cycling role in tropical African ecosystems. Detritus is of overwhelming importance in the diet of most species of freshwater crab. Given their high abundance and biomass, freshwater crabs are key to nutrient cycling in African rivers [20,27-28]. Freshwater crabs also play a role in disease transmission, and are vectors of the parasite that causes onchocerciasis (river blindness) in Africa, and an intermediate host of paragonimiasis (lung fluke) in Asia, Africa, and the Neotropics. The fact that paragonimiasis is a food-borne zoonosis indicates that freshwater crabs are widely consumed by humans.

Freshwater crayfishes, with more than 590 described species (though this number is continually being added to; [29]), are predominantly temperate in distribution, but are found in all but the Indian subcontinent and Antarctic continent. As for freshwater crabs, crayfish can serve as keystone species, but they also pose problems in many areas where they become invasive. Freshwater crayfishes are a very popular food item in many parts of the world such as Madagascar, where there is a sustainable fishery [e.g 30], and are also important to the aquaculture industry. Crabs and crayfishes are largely complementary in their distributions with the only significant overlap in ranges occurring at the edges of their distributions, such as in parts of Australia, Madagascar, and Central America (Figure 02). Freshwater crabs are concentrated in the world's tropical regions; the most species rich areas are in Southeast Asia where the two most diverse families occur. The Afrotropics are the least diverse of the tropical regions although a diverse species flock is present in Lake Tanganyika, the world's longest freshwater lake. The recorded diversity of freshwater crabs in South and Central America is relatively high but is certain to be an underestimate of the true number of species due to lack of adequate field sampling. In contrast, the freshwater crayfishes show centres of diversity in the southeastern Appalachian Mountains (USA) in the Northern Hemisphere and in south-east Australia in the Southern Hemisphere.

Endemic freshwater species have provided insights into the process of evolution. In one example, Lake Tanganyika's largest species of crab has a significantly enlarged claw, which it uses to crush snail shells and eat the mollusc inside. In the lake, there are also freshwater fish adapted to eat freshwater molluscs. To combat predation, some species of the lake's snails have evolved a heavily thickened shell, even some with long spines, more like marine gastropods, to resist crushing by predators.

Freshwater species have some amazingly complex life-cycles. For example, most species of freshwater mussels require a host fish to allow the young larvae to grow to juvenile status. These larvae (glochidea) lodge in the gills of freshwater fish, where they can spend several months before they drop off back into the mussel beds. The 'lures' that the fringing mantle of the mussels form with different colours and shapes look like female fish or even salamanders, thus enticing their host species to come in close for the release of the larvae.

Some freshwater species also occupy unusual habitats, which are not traditionally associated with freshwater, like the tree-hole crabs in Africa. The Liberian tree-climbing freshwater crab *Globonautes macropus* is endemic to the Upper Guinea forests of West Africa. It lives in the forests of Liberia and Guinea, in water-filled tree holes in closed-canopy primary rainforest. It can be found well away from permanent water sources, foraging at night on the forest floor, and climbing tree trunks to hide deep inside holes where rainwater collects. Unfortunately, the rainforest habitats on which these crabs depend for their survival are under serious threat, and deforestation is increasing in all parts of the Upper Guinea forest, particularly in Liberia [31].

Status and trends of freshwater invertebrates

At present, the IUCN Red List includes assessments of 7,482 species within the four taxonomic groups of odonates, molluscs, crabs and crayfish, which have been the focus of extensive assessment work over the past decade. These groups provide the best available data on the extinction risk of freshwater invertebrates, through the following data: i) comprehensive assessments of all known species of freshwater crabs (1,280 spp.) and crayfish (590 spp.) at the global scale; ii) a random sample of the world's freshwater molluscs [1,500 spp. (*c.* 30% of

Green drake mayfly (*Ephemera danica*) © Nick Upton / naturepl.com

Stonefly (Plecoptera) © Michel Roggo / roggo.ch

Coenagrionidae xanthocnemis © Bryce McQuillan

10,000–20,000 freshwater species are either extinct or at risk of extinction

the total number described)], and dragonflies and damselflies (1,500 spp. (26% of the total number described)), as compiled through the Sampled Red List Index project (SRLI – see Box 02 Chapter 1); and iii) all known described species for all four taxonomic groups within Africa and Europe. The information compiled through the SRLI project on molluscs and dragonflies and damselflies was designed to provide a picture of the global scale patterns of species richness and threats. Pan-African and European projects were initiated to provide comprehensive regional assessments.

A total of 7,784 freshwater invertebrates are currently listed on the IUCN Red List (2011.2, November 2011). Of those, 34% are considered threatened (Figure 03). The exact threat level is unknown, as the status of 2,504 Data Deficient (DD) freshwater invertebrate species is undetermined, but ranges between 23% (assuming no DD species are threatened) and 56% (assuming all DD species are threatened), with 131 species classified as Extinct, and four Extinct in the Wild. The current results show that gastropods are the most threatened group (51% of species threatened: range calculated as 33% - 68%), followed by bivalves (34%: 26-49), crayfish (32%: 24%-47%), crabs (31%: 16%-65%) and dragonflies (14%: 9%-44%).

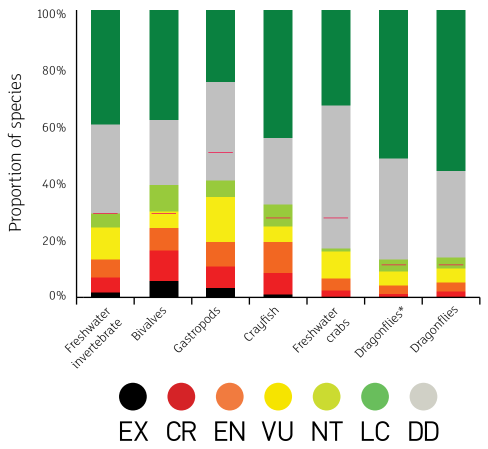
Overall, freshwater gastropods have the highest percentage of threatened species of the freshwater invertebrates assessed to date, reflecting the large number of very range-restricted species living in specialised habitats, where pollution, loss of habitat or sedimentation can have a big impact over very short timeframes. A sampled approach to assessing the freshwater molluscs [32-34], designed to allow global level comparison of threat scores across groups, specifically in response to the call for indicators via the Convention on Biological Diversity Strategic Plan [35], reveals more detail. Specifically, the assessment shows high levels of threat of around 40% in one of the major centres freshwater biodiversity in the world, the south-eastern USA. This area has high levels of diversity in species such as molluscs and crayfish; however, a number of threats, particularly impoundments of water courses and pollution, have caused many species of freshwater mollusc in the region to decline dramatically since the first half of the 20th century.

Dragonflies and damselflies tend to occupy more ephemeral habitats. This contributes to the lack of information about certain species and regions. They also display the lowest percentage of threatened species of the freshwater invertebrates (~10%), although some tropical areas known to be highly species-rich have yet to be comprehensively assessed. Threatened species are clustered in the tropics, especially in the Indo-Malayan and Australian biogeographic realms (Figure 04). This is largely due to the high percentage of endemics in the Indonesian archipelagos combined with the anthropogenic threat to the species of large scale logging of lowland forest on many islands, while in Australia, climate change is having an especially strong impact on freshwater systems. As in many other taxa, island endemic species are the most threatened. This is true both for species restricted to geographic islands, such as the Philippines, and habitat islands, such as remnant forest patches in Sri Lanka. The lowest threat level is found in the Nearctic realm, with about 80% of the species listed in the Least Concern category. The majority of the Odonata species depends on lotic (flowing) waters and on forest habitat. Species in lotic waters were found to be at greater risk than those in

Stream ruby (*Rhinocypha bisignata*) © P. Jeganathan

European crayfish (*Astacus astacus*) © Michel Roggo / roggo.ch

Figure 03 | IUCN Red List status of freshwater invertebrates.
* denotes findings are from sampled assessment.



Globonautes sp. © Neil Cumberlidge

lentic (standing) waters, while the threat level between the terrestrial habitat types is more or less identical.

Very little is currently known about freshwater crabs, with the highest proportion of species assessed in the Data Deficient category of all freshwater invertebrate groups (631 of the 1,280 crabs are classified DD). At present there is insufficient distributional data on many of these species, and so it has not been possible to fully assess their conservation status. However, semi-terrestrial crabs tend to be the most threatened taxa within the freshwater crabs. The distribution of threatened species appears to be fairly widespread with no particular centre of threat identified, though number of threatened species is particularly high in tropical Asian countries, which are at the global centre of freshwater crab diversity. Important concentrations of threatened species are found in the highland forests of Sri Lanka and Taiwan, and in the rainforests of Indochina, Thailand, the Malay Peninsula, Borneo, and New Guinea (Figure 02).

Aggregations of threatened crayfish species have been identified across the global range of this group (Figure 02). In Europe, a decline in stocks of native species has been recorded in many countries in the face of increasing populations of non-native species [36]. Most European countries retain at least one native species, but all are under threat from habitat loss, deteriorating water quality, overfishing, climate change, and most importantly from increased contact with non-native species and crayfish plague. According to Holdich *et al*. [36] the threat to native species is so great in some countries that sanctuary sites are being established. The three most widely-spread non-native species originate from North America the signal crayfish *Pacifastacus leniusculus*, the spinycheek crayfish *Orconectes limosus* and the red swamp crayfish *Procambarus clarkii*. These species out-compete their native counterparts, and may carry and spread pathogens such as crayfish plague.

Major threats to freshwater invertebrates

An analysis of threat processes (Figure 05) shows that water pollution is the major threat affecting freshwater invertebrates at a global level. Over 41% species are threatened by different types of pollution, specifically nitrate and phosphate run-off from agricultural sources, sewage from domestic sources and various pollutants from industrial sources. In Africa in particular, pollution from mining is also a serious problem.

The second-most prevalent threatening process comes from dam construction and water abstraction of water from rivers and groundwater for domestic supplies (especially in Europe) and off-take of water for irrigation of crops (Figure 06). These impact 26% of threatened freshwater invertebrate species. In central Africa, the major threats to species that are reliant on the waters of river rapids come from planned dam projects on the Congo River (e.g. Inga Dam project) or plans to dam the lower Tana River for irrigation schemes and hydropower with potential to impact flow regimes. This is a major threat to many range-restricted species which are dependent on the highly specialised habitats that rapids provide. The scale of dam development is set to expand greatly over the next few years.

Changes in freshwater systems due to residential or commercial developments pose the third most significant threat. Around 19% of threatened freshwater species are affected by loss of habitat as land is converted; for example, lowland floodplain marshes are drained to provide land for housing and industrial estates. In Africa, for example, logging activity has serious consequences for freshwater rivers, changing flow regimes, increasing water temperatures through loss of gallery forests and leading to increased sedimentation and pollution [37]. In the Rift Valley, deforestation along the rivers draining into Lake Tanganyika has resulted in severe sedimentation of the lake floor, a process which is threatening many of the lake's endemic species, especially crabs and gastropods that are particularly diverse in rocky near-shore areas. Similarly, aquatic invertebrates which spend their adult life as terrestrial imagoes, e.g. dragonflies (Odonata) or mayflies (Ephemeroptera), are also likely to be affected by these threats. Forest dependent species are often highly specialized and quickly outcompeted by invading openland species, once gallery forest and/or nearby forests are cleared. The growing mining activities in many parts of Africa are therefore likely to impact freshwater invertebrates, as

Figure 04 | Global map of threatened species richness for Odonata (dragonflies and damselflies), given as a proportion of those species assigned VU, EN and CR Red List categories. The apparent absence of threatened species in severely impacted regions, such as Madagascar and India's Western Ghats, is explained by the high proportion of DD species in those regions.

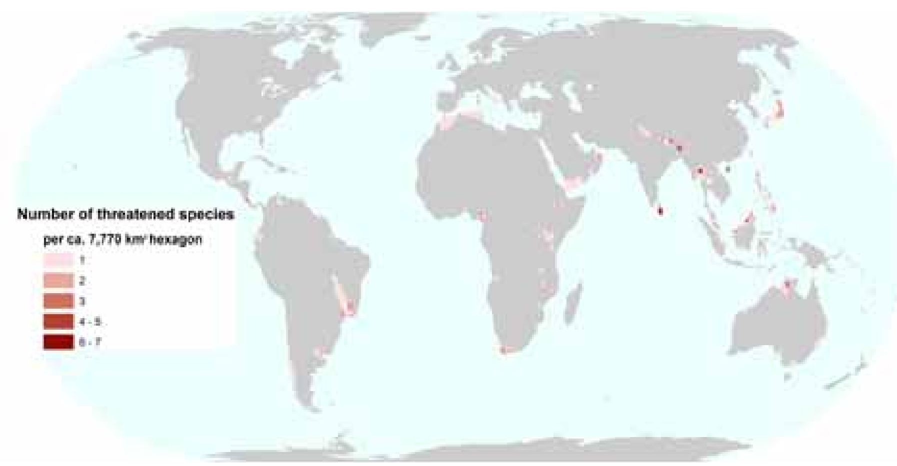
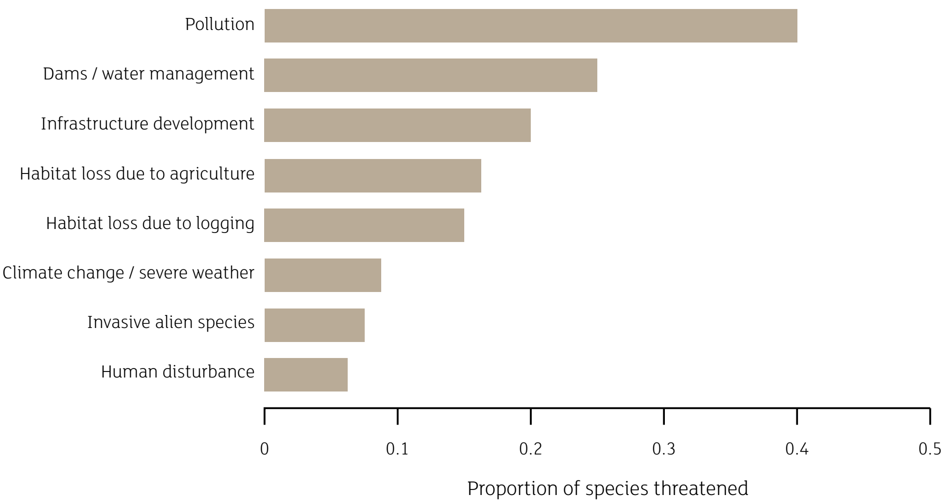


Figure 05 | Global threats to freshwater invertebrates on the IUCN Red List. Horizontal axis shows the proportion of threatened (CR, EN, VU) species affected by each of the threatening processes on the vertical axis. Note - these numbers may add up to more than 1 because species are often affected by multiple threats.



The majority of the estimated 126,000 freshwater animals are invertebrates

small scale mining often goes hand in hand with local logging activities and disturbs the water regime of springs and small streams and rivers.

At a global level, other threats, such as aquaculture, logging, climate change, invasive species and fisheries also impact freshwater invertebrates; some of these threats are likely to become more prevalent in coming decades. Climate change is already emerging as a serious threat to freshwater invertebrates in Australia, specifically affecting many range-restricted spring snails as springs dry up. The presence of invasive alien species currently threatens about 8% of native species, however, as climate change starts to have an impact, some of these invasive species may become a more significant threat. Invasive species play a major role as a source of threat to African freshwater invertebrates, specifically freshwater crabs. Species of freshwater crabs are threatened by the rapid spread of the non-native Louisiana crayfish (*Procambarus clarkii*) and the red claw crayfish (*Cherax quadricarinatus*) throughout the continent. These damaging aquaculture species are resilient, disperse easily, and eat almost anything, and are capable of causing dramatic ecosystem disruption and biodiversity loss wherever they establish themselves, causing (in the extreme) significant changes in populations and even extinctions (e.g. in Lake Tanganyika). The species may also modify the habitat thus making it unsuitable for native species. Non-native freshwater crayfish may spread previously unknown parasites into native populations of crustaceans and other animals. They have been reported (in other places) to carry a number of pathogens, including viruses, bacteria, fungi, protozoan and metazoan parasites.

At the same time as these diverse threat processes are affecting molluscs across the continent, no known targeted conservation measures are in place to protect any of these species. There are, with the exception of Ramsar Sites, few protected areas designed specifically for protection of freshwater fauna. The majority of protected areas include rivers and lakes as boundary markers rather than as targeted conservation features in their own right. Clearly, more protection is needed to safeguard freshwater invertebrates into the future.

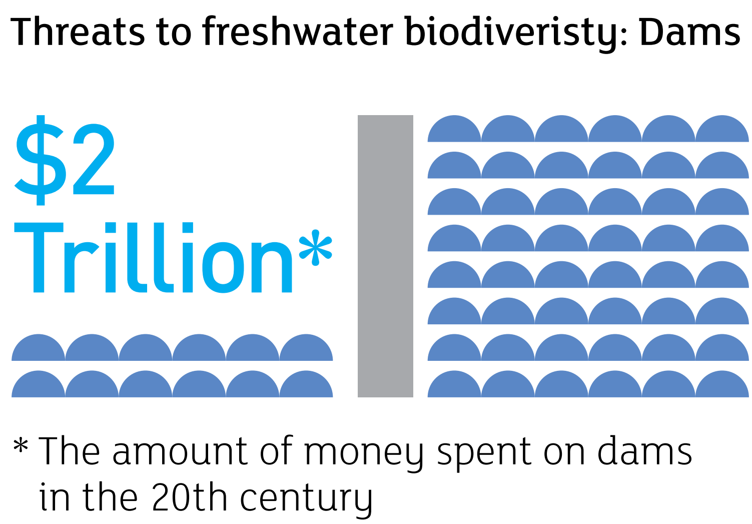
Ecologically and economically important species

Given the growing demand of humans, particularly the poorest, on freshwater resources (Figure 01), freshwater habitat and species conservation should be a priority. Freshwater invertebrates provide humans with many services, such as water filtration by filter-feeders, and contribute to flood protection as part of a diverse and functioning system. The disproportionately large contribution of freshwater invertebrates to such free services are often poorly appreciated and described, but nonetheless critical. In the UK, for example, it has been estimated that inland wetlands, with their intact invertebrate fauna contribute in excess of GBP £1 billion per year (Figure 07; [38]). The value of conserving wetlands for flood protection in the city of Vientiane (Lao PDR) was estimated at around US$ 5 million per year (based on the value of flood damages avoided; [39]).

Filter-feeding invertebrates, such as freshwater mussels, play an important role in the ability of freshwater systems to self-regulate; they aid water purification by removing phytoplankton, bacteria and organic matter from the water column, and aid nutrient cycling through excretion. Burrowing mussels and other burrowing macroinvertebrates increase oxygen and water content of sediment by stirring up the substrate and aid nutrient transfer from the water column to the sediment [40-42]. Mussels and other filter feeders can therefore make a significant contribution to freshwater health by providing a natural water purification plant. Furthermore, because of their sensitivity to changes in freshwater quality, these species provide a sensitive indicator of the health of the freshwater systems on which humans critically depend.

Freshwater mussels capable of producing

Figure 06 | USD $2 trillion has been spent on dams, one of the most prevalent threats to freshwater biodiversity, throughout the 20th century



high-quality pearls have been harvested by humans, with significant economic value [43]. Given the interest in the fishery and the sometimes non-selective methods used, such as using dredges to dislodge mussels, annual yields of freshwater mussels have declines dramatically over the years [43].

What we have lost

Most extinctions amongst freshwater invertebrates have been reported for molluscs, exceeding those reported for birds, mammals and amphibians. Three percent of gastropods and 5% of freshwater bivalves have been classified as Extinct. The current picture may well be worse for molluscs, as species are only listed as extinct following targeted surveys by skilled surveyors. A time-lag is therefore likely to occur between a species extinction, and the species being officially listed as Extinct. There are another 30 Critically Endangered species flagged as being possibly extinct, with insufficient survey data to confirm extinction. Further research is required on these species.

For example, the Southeastern USA is a major diversity hotspot for freshwater species. Molluscan diversity is high, yet so is the number of impoundments which have affected river courses throughout the region. Many species in the region have gone extinct, are considered as possibly extinct or are highly threatened with extinction. The Coosa Elktoe, a mussel once collected in the Coosa River, has not been found since the river's impoundment, and other gastropod species from the same river system have also vanished since, such as the Little Flat-top Snail *Neoplanorbis tantillus* and several species of *Elimia*.

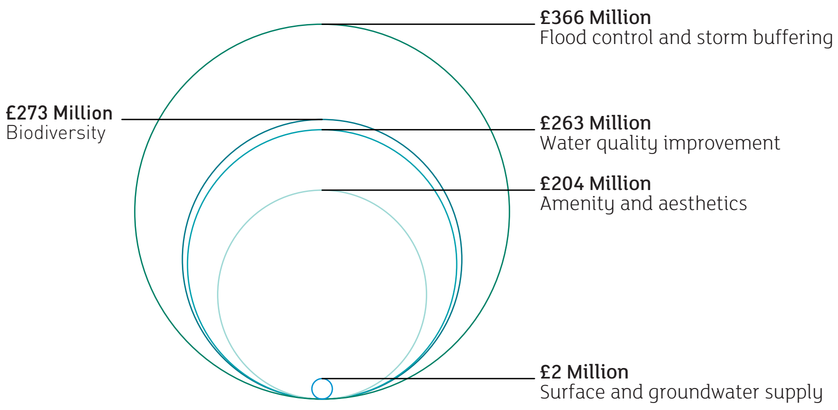
In further examples, two Mexican species of crayfish, *Cambarellus alvarezi* and *Cambarellus chihuahuae* were endemic to only a few small springs which have since dried up due to water abstraction to supply human demands. For *C. alvarezi*, this process was responsible for up to 15 continuous years of desiccation at the only location this species was found. With their habitat now gone, these species are considered extinct.

Conservation successes

Innovative solutions for removing non-native species have been trialled and found to be successful in several locations around the world. In North America, there are several invasive species, such as the zebra mussel (*Dreissena polymorpha*) and quagga mussel (*Dreissena bugensis*), which have had a major impact on ecosystems as well as the native molluscan fauna. The cost to industry of the clogging of water intake pipes by these species has led to large-scale investigations of non-detrimental solutions for removal. The development of 'biobullets', an encapsulated pellet of poison designed to be taken in by the water-filtering alien species but not their native counterparts, gives hope that such solutions may benefit the native fauna. These are now being explored in other regions, including New Zealand (D. Aldridge, pers. comm.).

Restoring populations of freshwater mussels has been achieved in several locations in the temperate regions. Large freshwater mussels are vital components of any freshwater system, particularly in water filtration. Therefore, the decline of many large freshwater mussel species over the last 100 years is of the utmost concern. Freshwater mussels have a long generation time, in some cases over 60 years, hence we have time to develop conservation breeding programmes as well as cleaning and restoring river systems to make the habitats suitable for reintroduction of the juvenile mussels. In Europe and North America, there is now extensive experience of conservation breeding programmes, often using fish farms, as many species require a fish host during the life cycle and these are now as successful as many zoos in maintaining species where their populations are no longer viable and hence conserving the broad genetic diversity of these species.

Figure 07 | Total value provided by UK inland wetlands for five ecosystem service-related goods. Data from Morris & Camino [44]. See UK National Ecosystem Assessment [38] for more detail.



Southern Hawker (*Aeshna cyanea*) © Mark Billiau

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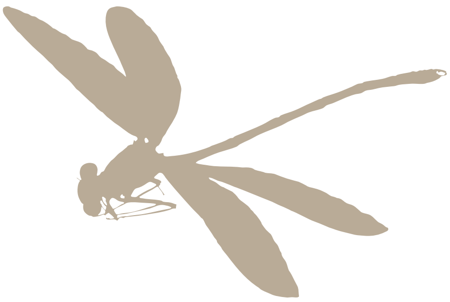
Blue damselfly © Ben Andrew



Chapter 3
Marine invertebrate life

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Introduction
Marine invertebrates are key components of all marine ecosystems, and play critical roles in essential ecological processes, food provision for humans, and diverse and productive food webs. Despite their importance, the vast majority of marine invertebrates are very poorly known. Research has tended to focus on the larger, more conspicuous and economically important species. Humans have long exploited the margins of pelagic ecosystems, but over the past five decades, rapid technological advancement has allowed more routine access to deeper waters [1]. Increasing exploration into the oceans that cover 70% of the world's surface has led to rapid advancement of species discovery and a greater appreciation of the marine system, but also greater risk to its occupants as human exploitation increased in extent and severity.

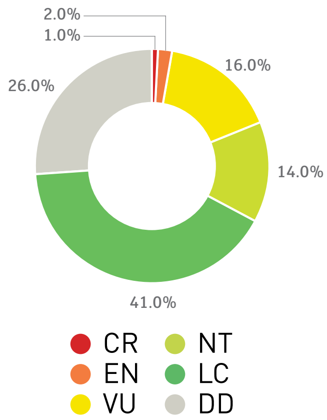
Diversity of the system
There are between 200,000 and 230,000 described marine species [2-3] and it is predicted that over two million exist in total [2]. Invertebrates make up over 75% of the described marine species [3] and over 95% of all marine animal species. Marine invertebrates can be extremely numerous - for instance nematodes are thought to represent 90% of all life forms on the ocean floor with as many as 1×10^8 species in the deep sea [4]. Planktonic copepods, which feed directly on phytoplankton, are among the most numerous. The Antarctic krill *Euphausia superba* is thought to be the most abundant species on the planet [5], sustaining vertebrate marine megafauna across the Southern Ocean.

Living in many different habitats from tropical waters to the polar seas, and from the surface to the abyssal deep, marine invertebrates have attained a huge diversity of forms, sizes and adaptations. For example, sizes of organisms range from microscopic zooplankton to the largest of all invertebrates, the giant squid *Architeuthis*, which is reported to be able to reach up to 18 m [6] due to the buoyancy of the surrounding water. The claws of the decapods (crabs and lobsters) are hugely variable, from the furry claws of the *Kiwa* crab, which hold the bacteria used to detoxify its food, to the massive spinose claw of the lobster *Dinochelus ausubeli*. Sea cucumbers, which make up a large proportion of macrofauna at depth and often move as herds hunting along the sea floor, have a body wall made up of catch collagen which has two states, either soft or stiff, that are under neurological control. This allows them to take refuge in tiny crevices and cracks. Also amongst the marine invertebrates we find the possibly longest-lived animal on Earth, the sponge *Scolymastra joubini*, which is found in the Ross Sea in the Antarctic and has been estimated to be over 15,000 years old [7].

Some marine invertebrates have unusual biology, such as the annelid worm *Eunice viridis*, whose rear end breaks off during the annual moonlit breeding spawn, rising to the surface of the water to release eggs and sperm in a milky, gelatinous soup whilst the head remains attached to the burrow on the sea floor. Sea spiders (pycnogonids) are one of the few animal groups where males care exclusively for the developing eggs by holding the egg mass on their legs until they hatch, and in some cases continuing to carry the juveniles. The violet snail *Janthina janthina* agitates the water with its foot to create bubbles which it binds with mucus to form a raft that allows it to spend its whole life drifting, feeding and breeding on the ocean surface in warm seas.

Significant gaps remain in global biodiversity data, and marine invertebrates, particularly those living within the tropics, are probably one of the groups that suffer most greatly from a lack of scientific attention, in part due to the great diversity of species at tropical latitudes, and in part due to the under-developed science base in these regions. New species of marine invertebrate are being discovered at an increasing rate, and scientists are still puzzled how species such as the tiny marine copepod *Ceratonotus steiningeri* could occur across both the Atlantic and the Pacific oceans and yet remain undiscovered until 2006 [1].

Figure 01 | Global status of marine invertebrates currently assessed on the IUCN Red List (1,306 species)



Nudibranch (*Chromodoris coi*) © Trond Larsen

Status and trends of marine invertebrates
There are currently 1,306 species of marine invertebrate included on the IUCN Red List [8]. This represents less than 1% of described species. Of the assessed species, around 25% are currently threatened with extinction. The exact level of threat is unknown, as 332 species (26%) are listed as Data Deficient (DD), but ranges between 20% (assuming no DD listed species are threatened) and 45% (assuming all DD listed species are threatened). Just over 40% of the world's assessed marine invertebrates are categorized as Least Concern (Figure 01).

Holthius's anemone shrimp (*Ancylomenes holtuisi*) © Barbara Moll

However, interpretations of these numbers have to be handled with care. The Red List contains some groups that have been comprehensively assessed along with isolated species that have been assessed for various other reasons, so the figure of a 25% global threat level may be misleading. There have been complete global assessments of reef-building corals, lobsters, and cuttlefish, and additional comprehensive assessments of squids, octopuses, cone snails, reef-building oysters and sea cucumbers are currently nearing completion. From already completed assessments, it becomes apparent that the conservation status of marine invertebrates varies greatly between groups, and data deficiency often poses an obstacle to assessment, for example, 76% of the 195 species of cuttlefishes and 35% of 247 species of marine lobsters are classified as Data Deficient.

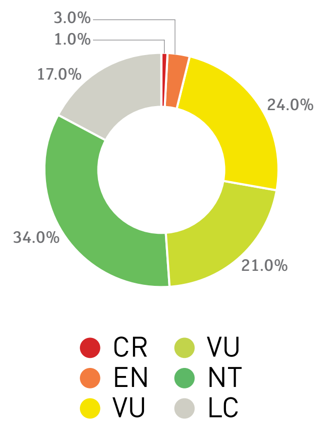
The greatest aggregations of threatened species on the Red List occur in Southeast Asian and South American waters, where over 25% of species are threatened with extinction. This is particularly worrying since the Indo-Malay-Phillippine Archipelago is an epicenter of marine biodiversity, known as the "Coral Triangle" because of its high coral and shorefish species richness [9-10].

Corals

Thirty-two percent of reef-building corals on the IUCN Red List are threatened with extinction (Figure 02; [11]: primarily order Scleractinia, but also reef-building octocorals and hydrocorals from the Helioporacea, Milleporina, and Stolonifera). Additionally, over 20% of species are listed as Near Threatened and are expected to move into a threatened category in the near future, unless threats are mitigated [11]. Seventeen percent of species are listed as Data Deficient, with over half of these belonging to the ecologically sensitive Acroporidae family. Corals have high sensitivity to environmental challenges since they host photosynthetic symbionts that are thermally sensitive, making the holobiont (both symbionts together) susceptible to bleaching. There is evidence that corals may also be metabolically dependant on their symbionts [12]. Once bleached, corals are nutritionally compromised, so are more vulnerable to other threats such as disease or predation from the crown-of-thorns starfish [11].

The Indo-Malay-Philippine Archipelago is the region with the highest species richness and largest number of threatened coral species (Figure 03), as well as having high levels of climate-change-susceptible species [11,13]. The South and Eastern Pacific have lower numbers of threatened coral species but high levels of endemism, in areas such as the Hawaiian Islands [14]. However, in some areas where there is low species richness, 90% of all species are not threatened but are susceptible to climate change meaning that they are likely to be subject to rapid decline should large climatic change occur [13]. These areas include the Mediterranean extending to north-west Africa, the east and southern coasts of the United States, north western Mexico, south-east Brazil, the East China Sea and smaller areas around Australia.

Figure 02 | Global status of reef-building corals (855 species)



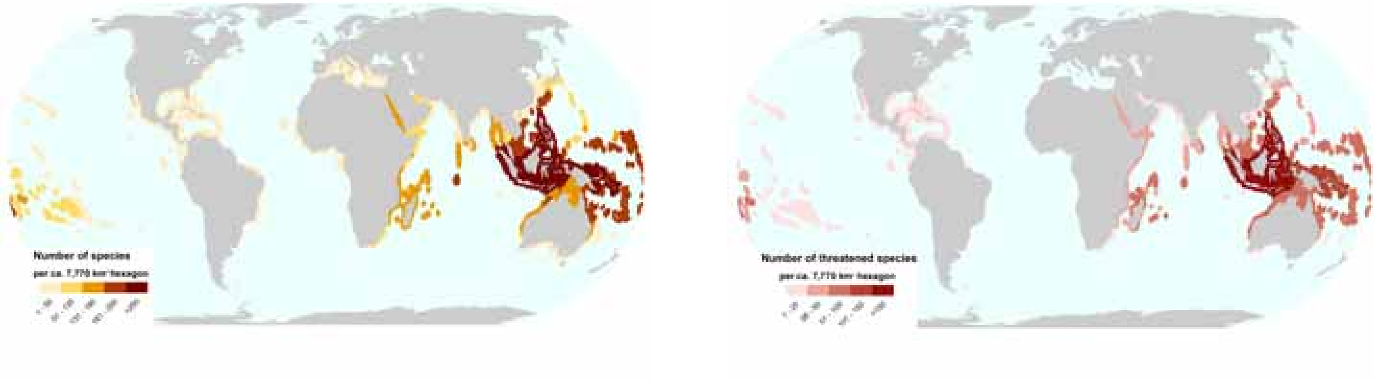


Figure 03 | Global distribution of reef-building corals for total species richness (left) and threatened species (right).

The biggest threat to corals is large-scale oceanographic changes associated with climate change; 233 of the 234 threatened species are affected by this threat. Typically found in clear, shallow tropical waters, reef-building corals are very susceptible to bleaching when exposed to raised temperatures and high solar radiation. Ocean acidification also reduces carbonate ion concentrations in seawater and thus the ability for corals to build their skeletons. Despite evolutionary persistence through the high temperatures and CO_2 levels of the past, it remains questionable how well reef-building corals will adapt to rapid environmental change on ecological time scales [12]. An analysis of the 2008 IUCN Red List of Threatened Species reported that 19% of already threatened reef-building corals are also climate-change-susceptible (i.e. they shared a number of ecological traits that pre-dispose them to elevated levels of threat to the impact of climate change), while 9% are threatened for other reasons, such as pollution, coastal development or degradation from destructive fishing or other anthropogenic activities. On top of this, 51% of corals listed in non-threatened categories share those same climate-change-susceptible traits. The logical conclusion is that more than three quarters of all the warm-water reef-building coral species could be at risk of extinction if climate change became more extreme globally [13].

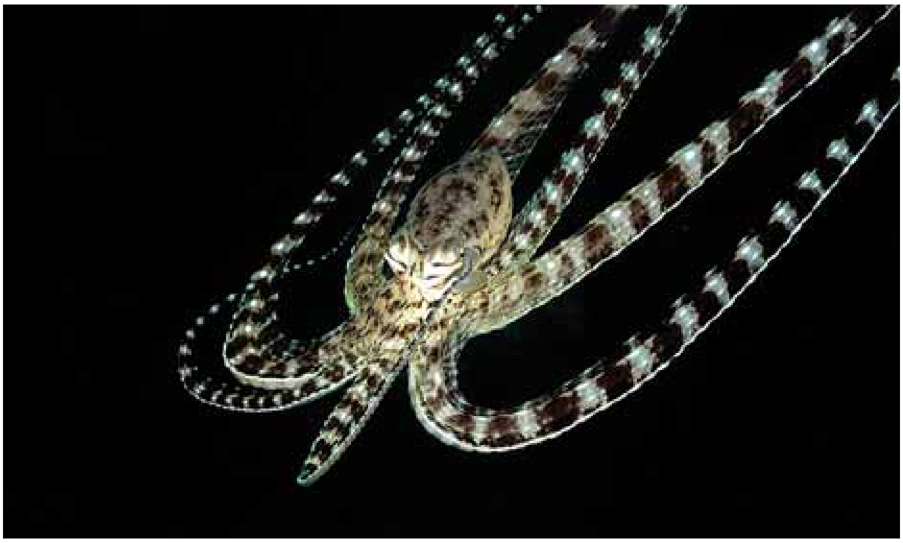
One eighth of the global population - about 850 million people - live within 100 km of a reef [15], therefore local-scale residential and commercial development, human disturbance and pollution also pose significant threats. High levels of local pollution have been shown to affect coral growth, for example causing skeletons to be more brittle thus making them more susceptible to destructive forces [16]. Fishing can result in direct physical damage through destructive practices, and the removal of keystone species and functional groups, often in conjunction with pollution, leaves reefs far more susceptible to invasion of coral predators such as crown-of-thorns starfish, which can cause very high rates of coral mortality on reef systems [17]. Invasive species introductions due to aquaculture, ballast water exchange of cargo ships or aquaria-related incidents also lead to unpredictable negative impacts [17-18].

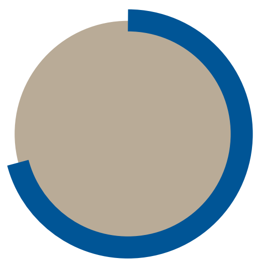
According to a recent report, left unchecked, local- and global-scale pressures combined are projected to lead to 90% of coral reefs being threatened by 2030 and nearly all reefs being threatened by 2050 [15].

Cephalopods

Comprehensive assessments of the approximately 600 cephalopods are due to be completed in late 2012. Most recently, a comprehensive assessment of all 195 cuttlefish was published on the IUCN Red List. The majority of species was listed as Data Deficient (76%), with only *Sepia apama* classified in the Near Threatened category; another 24% of species were listed as Least Concern. While many species of cuttlefishes are exploited, the fishery for *Sepia apama*, despite targeting only 15% of the total range of the species in the Spencer Gulf of southern Australia, affects a breeding aggregation and has caused massive population declines [19]. Preliminary data for oceanic squid have classed 57% as Least Concern, with the remaining 43% classed as Data Deficient. Many of the Data Deficient species have only been captured once or a few times, in trawler

Mimic octopus (*Thaumoctopus mimicus*) © Barbara Moll





71% of the Earth's surface is covered by ocean

Veined octopus (*Octopus marginatus*) © Barbara Moll

Box 01 | Nautilus - Living fossils

The order Nautilida contains the last species of externally shelled cephalopods, derived in the Cambrian over 500 million years ago and often described as a living fossil. Two genera (*Nautilus* and *Allonautilus*) are currently recognized and the once globally distributed group is now restricted to the benthos of steep coral drop-offs within the Indo-Pacific region.

It is difficult to estimate the size of wild *Nautilus* populations since they live in remote habitats beyond the reach of observational divers [21]. Shell collection for curios has had a big impact on the pearly nautilus, and also live collection for the aquarium, pet and exotic meat trades. At least ten countries export nautilus curios to the United States, with the most exports coming from the Philippines and Indonesia [22]. Nearly 800,000 products were exported from wild sources over a five-year period and a further 6 tonnes of shells and shell-derived jewellery were also exported [22].

Slow growth and reproduction and any exploitation may diminish populations of these beautiful and evolutionary distinct species even more. For example, experiments in aquaria have indicated that eggs take more than a year to hatch. Eggs are laid intermittently at a rate of 1-2 eggs per month and egg-laying can continue for several years. A recent study around Osprey Reef in the Coral Sea, Australia [21], suggested a maturation age of 15-16 years and a lifespan of more than 20 years. Dunstan *et al*. [21] suggest, as have others previously, that their low growth rate, slow reproduction, lack of dispersal options and low population numbers make this species particularly vulnerable to over-exploitation. Conservation assessments are urgently needed to ensure protective management actions are implemented to ensure the long-term survival of these living fossils.

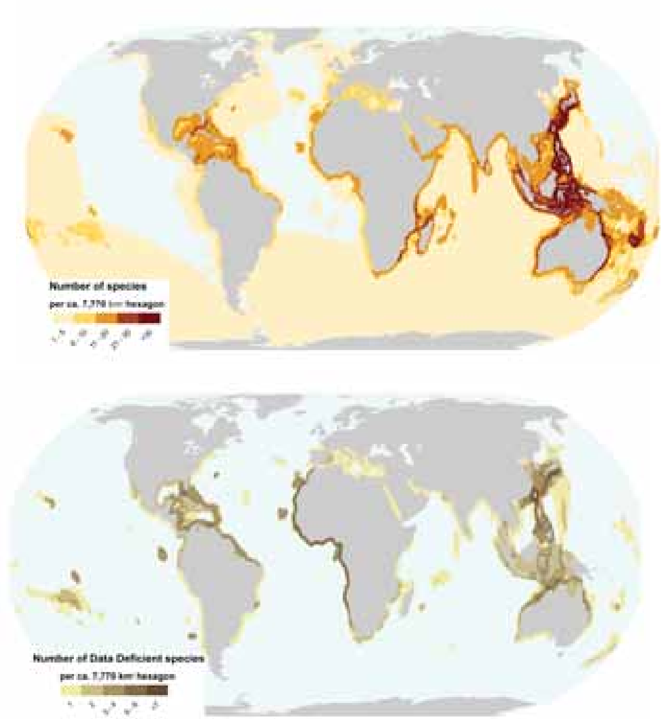
or deep-sea nets, so that nothing is known about their ecology.

Taxonomy also remains a problem, and little is known about many of the oceanic squid species classed as Least Concern, apart from that they occur in widespread locations where anthropogenic impacts are somewhat lessened and in habitats that are not easily targeted by fisheries. Coastal species of squid are more heavily targeted than their oceanic counterparts, and often specifically as a food source, so that ongoing assessments need to consider often poor quality fisheries data in order to determine extinction risk. Preliminary data for octopods indicate that one group of cirrate octopods, the family Opisthoteuthidae, may be particularly vulnerable to human activities. Cirrate (or finned) octopods tend to live in deeper waters, but the family Opisthoteuthidae inhabits depths targeted by deep-water fisheries, and are therefore often caught as bycatch. Furthermore, the suspected long life cycle and known low fecundity of these species make their populations slow to recover from fisheries induced decline. One species, *Opisthoteuthis chathamensis*, used to be taken regularly in the Orange Roughy fishery off New Zealand but has not been seen for more than 10 years [20] and is therefore assumed to have suffered a serious population decline. Of the 20 species in the genus *Opisthoteuthis*, nearly all are Data Deficient - we simply know so little about these deep-water species - but several are known to have been impacted by fisheries. No populations are known to be unaffected.

Lobsters

Lobsters are globally widespread, with a distinct centre of species richness reaching from Japan to the Coral triangle of the Indo-Pacific (Figure 04). Although the primary

Figure 04 | Global distribution of lobsters: species richness (top) and distribution of Data Deficient species (bottom)



Imperial shrimp riding nudibranch (*Periclemenes imperator* and *Risbecia tryoni*) © Christopher J. Crowley

Marine Protected Areas cover less than 3% of the ocean threat to 115 of the 247 comprehensively assessed species of lobster are fisheries, 65% of species are listed as Least Concern. Ecologically and biologically, lobsters are relatively resilient to harvesting pressure. For many species, specialist fishing methods, such as lobster potting and collection by divers, are required due to their preference for rocky habitats, meaning that they are not exploited in the significant quantities that would be expected from non-selective methods such as trawling. In addition to this, many of the species have circum-basin distributions, e.g. they are known from the East and West Pacific and the West Atlantic, and occur at depths greater than 2,000m. At such depths, accidental capture in fisheries is of little concern to long term persistence. Further, some species of lobster use ocean currents for larval dispersal, and this has allowed some heavily-exploited populations to recover rapidly once fishing has ceased.

Despite the specialist fishing methods required for many species, there are some heavily-exploited species occupying very broad geographic ranges. The Caribbean Spiny Lobster *Panulirus argus* ranges from Bermuda to Brazil and is exploited in every country in which it is found. In the north of its range, fisheries data indicate population stability. However, in the Bahamas, Brazil and Nicaragua fishing effort data are lacking, making it difficult to assess global trends. The Cape Verde Spiny Lobster *Palinurus charlestoni*, the only species assessed in a category other than Least Concern or Data Deficient, has been listed as Near Threatened, as it is undergoing harvesting pressure and population declines in parts of its relatively small geographic range.

A lack of monitoring in many fisheries contributes significantly to the 35% of lobster species listed as Data Deficient, with many Data Deficient species having been recorded in East Asian waters (Figure 04). Fisheries in East Asia and West Africa typically report catches of lobsters within multi-species catches (e.g. Japanese Mitten Lobster *Parribacus japonicus*), making it difficult to gather reliable data on landings of a particular species. Reliable inferences on trends are further complicated by a lack of data on fishing effort in these regions. However, the St. Paul Rock Lobster *Jasus paulensis* has been listed as Data Deficient because of the recent discovery of new unexploited populations on neighbouring seamounts. While heavily-exploited in the St Paul and New Amsterdam Islands Exclusive Economic Zone (EEZ), recent discoveries elsewhere have significantly expanded its range.

Cone snails

Most marine gastropods belonging to the genus *Conus* inhabit the shallow warm waters around coral reefs and mangroves. They commonly live from the inter-tidal to depths of fifty metres, however some species prefer the soft-sediment of bays or the deeper parts of continental shelves [23]. There are around 640 species of cone snail described, all of which are currently undergoing Red List assessment. Of these, the greatest proportion occurs across the tropical Indo-Pacific, with only 200 species

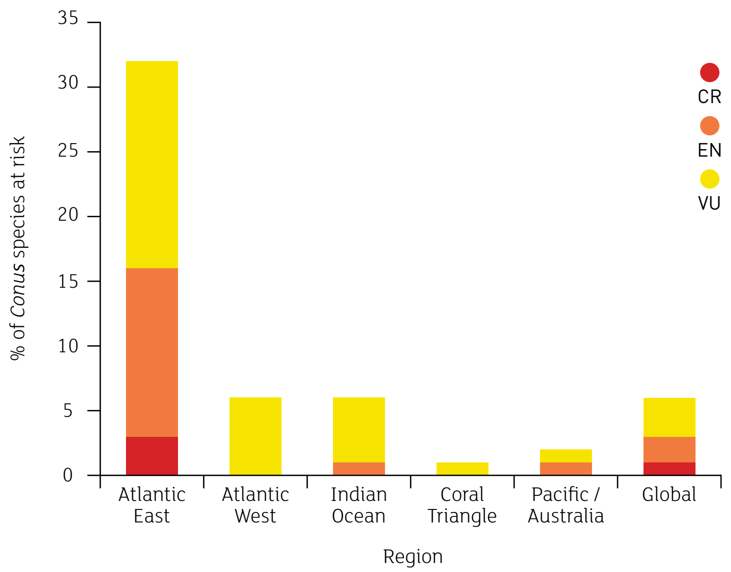
Peacock mantis with eggs (*Odontodactylus scyllarus*) © Christopher J. Crowley

found in the Atlantic. In higher latitudes, diversity is low with often just a single species occurring in some localities; however, a few cone snails can be found in warmer waters of the Mediterranean, the Red Sea, the southern shores of Japan, and California as well as Easter Island [23]. Distribution patterns vary widely, from endemic species restricted to small islands and archipelagos such as Cape Verde, to wide-ranging species found across the entire Indo-West Pacific.

Preliminary data suggest that in common with other marine molluscs, cone snails are threatened by habitat loss especially in regions suffering from marine pollution, sedimentation, coastal development or destructive fishing practices such as dredging. Alongside this, the explosion in mass travel to once remote regions coupled with the growing popularity of scuba diving has increased the pressure on live specimens gathered for their shells, including some of the rarer species. Species that have large or attractive shells, occur in shallow water, are endemic or have a restricted geographical range are at particular risk. Internet marketing has expanded the shell trade into a global business and collecting has reached unprecedented levels in some parts of the world. Despite this, there are only a few entries for marine mollusc species listed under CITES.

Provisional results indicate large variations in species status depending on their geographical distribution (Figure 05). The Eastern Atlantic region contains the greatest proportion of threatened species and includes the Cape Verde archipelago, which is home to 49 species of cone snail, 47 of which are found nowhere else in the world. Most of the threatened species in this region have highly restricted ranges, at times occupying a single bay or seamount. This increases vulnerability to anthropogenic pressures such as port construction, tourism development, pollution from major conurbations, and shell gathering by tourists and for the retail and specimen shell trades. On the other hand, the waters of the Indo-Pacific, particularly within the Coral Triangle, have few threatened species, are rich in diversity and benefit from species having wide distributions with many small marine protected areas (MPAs) providing safe havens.

Figure 05 | Extinction risk varies across regions for cone snails. Note: where a species occurs across more than one region it has been allocated to the region that is central to its known distribution.



Ecologically and economically important species

Marine invertebrates comprise many species with ecological and economic importance. From unassuming herbivores to highly efficient predators, marine invertebrates have huge importance within the ecosystems they inhabit and can provide habitats for numerous other species to thrive. For example, coral reefs are estimated to cover only 0.1-0.5% of the ocean floor [15,24], yet they provide the unique architecture on which reef organisms depend. Within their three-dimensional structure are a huge number of ecological niches for an estimated 60,000 reef-dwelling plants and animals to exploit [25]. They offer environments for spawning, nursing, breeding and feeding and are a source of excess organic production, resulting in a net flow of biological support to seagrass beds, mangroves and open-ocean [24]. As a result, they support around a third of described marine species [17] and a quarter of marine fisheries [12,26] on which tens of millions of people worldwide depend for their protein intake and livelihoods [27].

Coral reefs protect the shoreline from storms and erosion and provide sheltered areas for the build up of land, or the growth of seagrass and mangrove ecosystems. They provide ecological goods such as food, curios, raw materials for medicine, and fish for the aquarium trade. Coral reefs also play an important role in geochemical cycles such as global carbon and calcium balance and sequestration of waste from human populations.

Global ecosystem services provided by coral reefs, such as subsistence and commercial fisheries, coastal protection and tourism have been estimated to have a value of $375 billion per annum (Table 01; [28]). It has been estimated that reef degradation in the Caribbean spanning the period from 2000-2015 could result in net revenue losses from reef fisheries of US$ 95-139 million [29]. The annual value of coral reefs, mangroves and associated natural habitats is estimated at a total of US $2.3 billion [30].

American and European lobsters (*Homarus americanus* and *Homarus gammarus*) are possibly the most fished species in the world. Commercial landings in Maine in 2011 are estimated to a value of almost $US 335 million and yet records have shown that populations of these species are increasing in some areas. American lobsters in the Gulf of Maine have abundance estimates well above the target of 69.92 million lobsters [31], with estimates of about 100 million individuals in 2003 [31] and the data suggest that abundance is increasing. Managed lobster fisheries may not only provide sustainable food but also add a significant contribution to the economy in these areas. Other marine invertebrates, both wild and farmed, provide important food sources to humans, often with high economic value to the fishery (Figure 06; [32]).

Zooplankton is significantly important both economically and ecologically. It consists of permanent members called the holoplankton (diatoms, radiolarians, dinoflagellates, foraminifera, amphipods, krill, copepods, salps) and temporary members such as larval forms of sea urchins, sea stars, crustaceans, marine worms, marine snails, and most fish. These organisms are a vital link in marine food chains and their biomass and abundance can be used to determine the health of ecosystems, specifically as they are sensitive to nutrient levels, temperatures, pollution, levels of light and increases in predation. Baleen whales living in the Southern Ocean feed predominantly on Antarctic krill, which may be negatively affected in years to come by warming seas and expanding krill fisheries [33]. Similarly, abundance of Adélie and chinstrap penguins has been linked to trends in krill biomass, explaining why populations are currently decreasing in response to climate change [34].

Many invertebrates are important to nutrient flows within marine systems. For example, sesarmine crabs are one of the only species that feed on mangrove leaves, thus making this productivity available to other species within the ecosystem. Their burrowing activity also aerates the soil making them essential to the successful functioning of these delicate systems. Similarly, polychaete worms are a widely distributed, abundant, ecologically important food source for fish and birds, and sediment mixing by them and others contributes to vital nutrient cycling services.

All systems, marine, terrestrial and freshwater, are intricately interconnected via climatic, geological and ecological processes. In terms of ecological interconnectivity of systems, many commercially landed marine fish rely on insects, as well as marine invertebrates, as a food resource for at least part of their life cycle. The value of commercially landed fish that critically rely on insects has been estimated to be worth hundreds of millions of dollars (Table 02; [35]).

Figure 06 | Value of shellfish production in the UK [32]

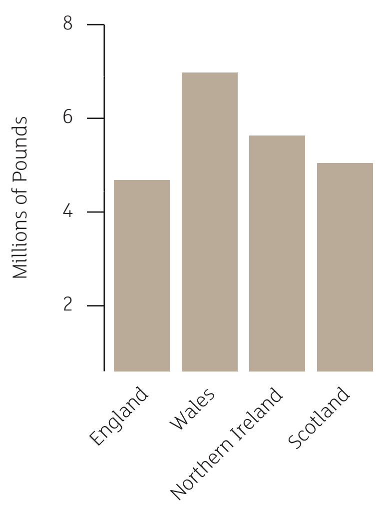


Table 01 | The average global value of annual ecosystem servicesprovided by coral reefs (Costanza *et al.* [28])

Ecosystem service	Value p/ha p/year (1994 US$)
Disturbance regulation	2,750
Waste treatment	58
Biological control	5
Habitat/refugia	7
Food production	220
Raw materials	27
Recreation	3,008
Cultural	1
Total value per hectare (ha^{-1} yr^{-1})	**6,075**
Total global flow value ($\$yr^{-1}x10^{9}$)	**375**

Squat shrimp (*Thor amboinensis*) © Barbara Moll

Red pencil urchin © Heather Hillard

Red rock crab (*Grapsus grapsus*) Trond Larsen

Fully protected marine reserves cover less than 1% of the ocean

Crinoids © Trond Larsen

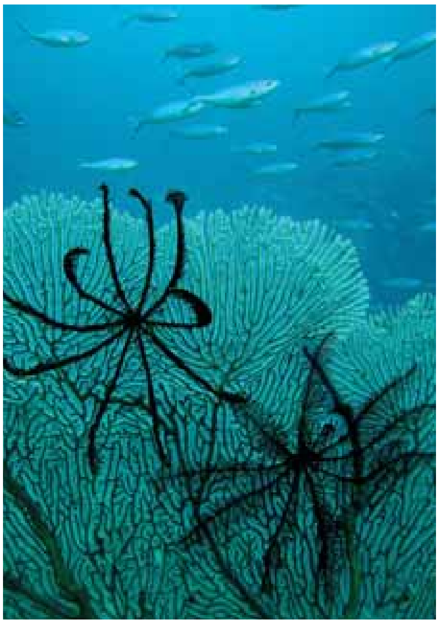
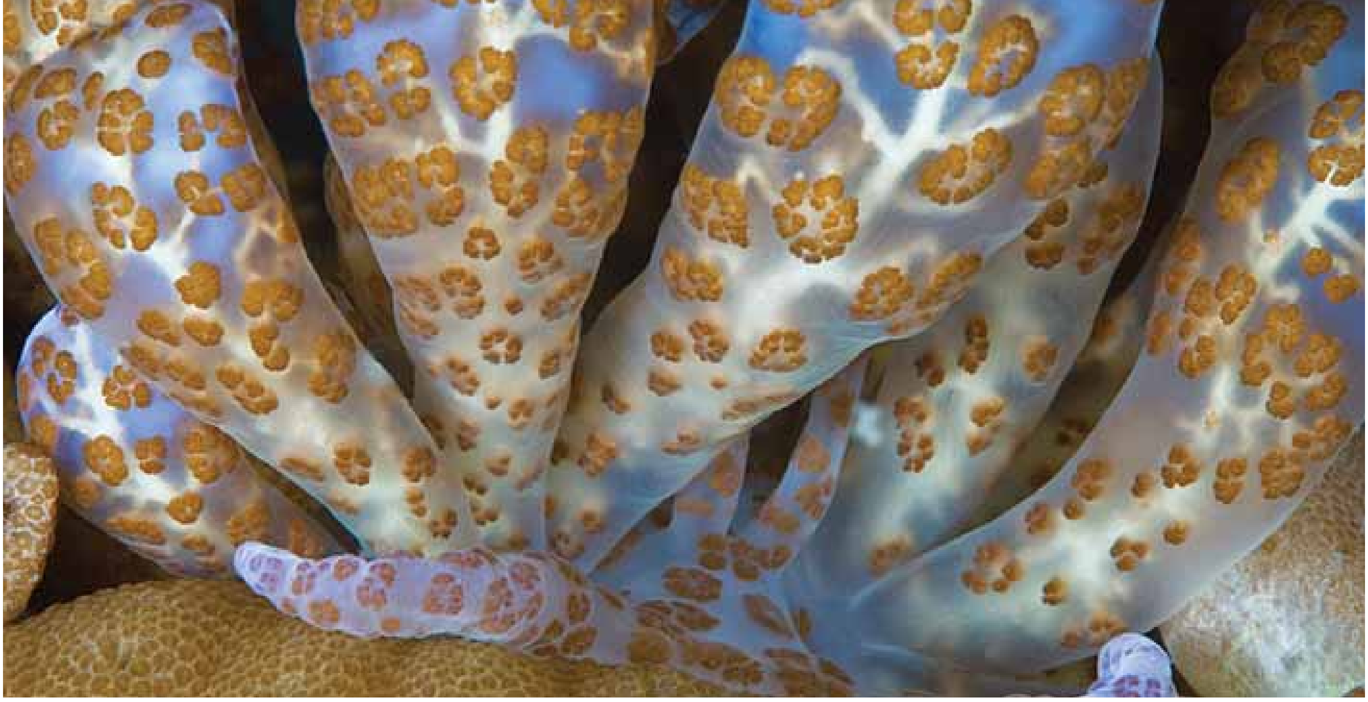


Table 02 | The value of commercially landed fish that rely upon insects as a critical nutritional resource [35].

Commercial fishing saltwater species	**Weight** (kilograms of fish landed)	**Value** (millions of dollar)
Alewife	1,675,935	0.38
Mullet, striped	15,473,230	9.5
Mullet, white	509,887	0.24
Mullets	444,900	0.31
Mummichog	4,590	0.01
Perch, white	2,482,006	1.08
Perch, yellow	1,714,342	2.91
Salmon, chinook	27,345,066	32.63
Salmon, chum	92,031,758	16.9
Salmon, coho	32,256,133	15.26
Salmon, Pacific	176	0.0005
Salmon, pink	334,080,474	24.76
Salmon, sockeye	184,505,904	109.9
Shad, American	2,074,686	1.19
Shad, gizzard	5,306,259	0.7
Shad, hickory	88,339	0.02
Smelt, eulachon	1,081,152	0.16
Smelt, rainbow	489,467	0.73
Smelts	480,212	0.15
Suckers	157,164	0.045
Tilapias	5,482,778	1.22
Trout, lake	558,129	0.23
Trout, rainbow	308,306	0.19
Walleye	25,810	0.04
Whitefish, lake	8,064,823	6.05
Total	**716,641,526**	**224.6**



“Solar-powered” nudibranch (*Phyllodesmium longicirrum*) © Christopher J. Crowley

‘Blue Biotechnology’ is a term used to describe the marine or aquatic application of biotechnology. A wide range of uses are known: potent neurotoxins from snails are used as a painkiller and compounds from crustaceans and sea fans in cosmetics, a novel glue has been isolated from mussels, fluorescent compounds have been derived from jellyfish and artificial bone can be made from corals [36]. Cone snails employ complex venoms to immobilize their prey of fish, molluscs and worms. Each species’ venom is a unique composition of multiple peptides or ‘conotoxins’ which together provide an arsenal of over 50,000 toxins across the genus [37]. Some of these show great promise in biomedical research and even with the relatively small number under study, the capability of conotoxins to target a broad range of highly-specific cellular receptor sites holds unparalleled promise for both their diagnostic and human therapeutic potential. The first approved example is Prialt® (Ziconotide) developed from the snail *C. magus* for the treatment of severe chronic pain and the prevention of stroke [38]. Other current research and development potential for *Conus* toxins lies in the diagnosis and treatment of conditions as diverse as cancers, hypertension, epilepsy, arrhythmia, asthma, multiple sclerosis, and diabetic neuropathy [39-40].

What we have lost

There are currently four marine invertebrate species listed as Extinct on the Red List: the minute salt marsh snail *Omphalotropis plicosa* endemic to Mauritius; *Littoraria flammea*, a marine gastropod mollusc from the periwinkle family, endemic to China; *Collisella edmitchelli*, a gastropod mollusk, once endemic to the United States; and the eelgrass limpet *Lottia alveus* which was once widespread along the eastern seaboard of the United States and Canada, but is now known as the first marine invertebrate recorded to have been driven to extinction, with a last reported sighting in 1933. It is thought that mold infected the seagrass *Zostera marina* on which it lived and that the decline of its habitat led to the gastropod’s demise [41].

Fifteen species are currently listed as Critically Endangered on the IUCN Red List. These include six scleractinian corals and a hydrocoral, one polychaete worm, four species of crustacean (all marine planktonic copepod species restricted to single caves in Bermuda [42-43]) and three species of gastropod mollusc, including two small South African endemics and the large edible sea snail *Haliotis cracherodii* (black abalone). The black abalone was once abundant on the West Coast of North America, but has shown population declines of more than 80% since the 1980s as a result of overfishing and the wasting disease Whithering Syndrome. Two iconic Caribbean species of *Acropora* coral, the Staghorn coral and the Elkhorn coral, are listed as Critically Endangered. Though both formerly widespread, these shallow-reef species have experienced significant population reduction exceeding 80% over the past 30 years, in part again due to the effects of disease, as well as other climate change and human-related factors. Because Caribbean reefs have been particularly devastated in recent years by a number of cascading impacts that include hurricanes, global warming, coastal development, invasive species, harmful fishing and tourism activities and the removal of key herbivores that control algal growth by overfishing and disease, many coral species

Candy crab (*Hoplophyrs oatesii*) © Barbara Moll

Blue-ringed octopus (*Hapalochlaena* sp.) © Barbara Moll

are hugely susceptible to negative impacts, specifically from climate change.

Restricted range species suffer a particularly high risk of extinction. For example, highly range-restricted endemics from groups such as sea cucumbers and cone snails, occurring particularly in shallow waters near extensive human developments, are highly susceptible to pollution of their coastal waters, and are likely to join the ranks of Critically Endangered species as more marine invertebrate assessments become available. Recent assessment of marine cone snails of the genus *Conus* has resulted in three species from Cape Verde, *C. lugubris*, *C. mordeirae* and *C. salreiensis*, to be listed Critically Endangered owing to their highly restricted ranges and declining quality of habitat from coastal tourism development and harbour construction.

Ultimately confirming the extinction of marine invertebrates is, however, highly challenging. Because direct observation in water is restricted (e.g. by scuba diving), verifying that species have been lost from their entire range is near impossible. As a result, scientific assessments of extinction may err on the side of caution, if surveys are deemed to be insufficient to confirm extinctions. For example, the deep-water octopus *Opisthoteuthis chathamensis* has not been seen for over 10 years and is listed as Nationally Critical on the New Zealand Red List [20]. However, comprehensive surveys are needed to confirm the extinction of this species, for which funding is unlikely to be given. Previously common on the Chatham Rise, the species was regularly found in deep water fisheries by-catch. There have been estimates of a greater than 70% population decline in recent years [20]. This species belongs to the shallowest dwelling genus of the cirrate octopods, meaning that it lives within the capacity of commercial deep-water trawlers. It also lives in close association with the benthos, meaning that they are more easily caught in bottom-trawling nets, and their long life cycle and slow maturation make them very susceptible to fishing pressure.

Conservation successes

With the many threat processes affecting marine ecosystems and their inhabitants, a number of novel and established conservation approaches have to be adopted to ensure the continued survival of marine ecosystems and the important services they provide. Designation of Marine Protected Areas is likely to play a key role in marine protection into the future. For example, the Great Barrier Reef Marine Park's highly protected 'no-take' zones previously occupied less than 5% of the total park area [44], with areas specifically focused on coral reef habitats and remote 'pristine' areas. This did not provide adequate protection, potentially exposing some species to extraction throughout their entire geographic range [17]. The park underwent re-zoning in 2004, with the involvement of local communities, ensuring that all resource extraction was prohibited via a network of no-take zones across one-third of the park. Similarly, global assessments of coral species have led to sub-global initiatives to strengthen marine conservation policy and actions targeted at specific threat processes. For example, the multilateral and multi-agency Coral Triangle Initiative has been adopted by six countries in the region and includes the designation and effective management of priority seascapes, an ecosystem approach to the management of fisheries, establishment of effectively managed Marine Protected Areas, adaptation of climate change measures and improvement in the status of designated threatened species. With the 2020 Aichi targets calling for at least 10% of protection of marine areas, the focus on establishment of marine protected areas is likely to increase into the future. In 2010, the British Government announced the designation of the world's largest marine protected area, the Chagos archipelago, which represents 16% of the world's fully protected coral reef and 60% of the world's no-take protected areas [45]. No-take zones specifically are highly valuable to marine conservation. A reef-resilience assessment of the Pemba Channel Conservation Area off the Tanzanian coast showed 'no-take' zones having much higher levels of coral cover (86%) and diversity than areas of the reserve where certain fishing practices were still allowed [18].

Because of the threat from harvesting affecting a number of marine invertebrates, the establishment of sustainable fisheries is vital to safeguard supplies into the future. The Western Australia rock lobster (*Panulirus cygnus*) fishery was first certified as sustainable by the Marine Stewardship Council in March 2000. The requirements are strict and include seasonal closures, minimum size requirements and a ban on catching breeding females. There has been a significant reduction in the volumes of lobster taken from the fishery since 2005/6 due to a catch quota management system being put in place. This ensures sustainability of lobster stocks and the fishery remains the most valuable single-species fishery in Australia at an estimated value of $200 million per year and with 500 million tonnes of lobster caught in 2010/2011 [46].

Climate change is recognized as a principal emerging threat to many marine invertebrates, specifically corals, and establishment of conservation strategies to maximize adaptation potential and survival of coral reefs into the future represents one of the major challenges. Novel techniques such as remote sensing and ocean-atmosphere climate models are used to predict bleaching events, while conservationists aim to reduce and mitigate the impact of bleaching on reefs. However the success of this is dependent upon a number of factors including knowledge of how much and which corals are lost, the ability of those remaining to adapt to the higher temperatures, the balance between reef accumulation and bioerosion, and the ability to re-establish levels of herbivory, macroalgal cover and coral recruitment to those conducive to a healthy, resilient ecosystem [47].

Bloody Henry starfish (*Henricia sanguinolenta/oculata*) © Nick Upton / naturepl.com

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Crinoid © Trond Larsen

Chapter 4
Terrestrial invertebrate life

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Introduction

Terrestrial invertebrates fall into nine phyla including one that is exclusively terrestrial (the onychophoran velvet worms). The majority of species are contained within the extremely diverse phylum Arthropoda (which includes insects). Other phyla contain the burrowing, crawling or parasitic worms (Nematoda, Nemertea, Annelida, Platyhelminthes, Acanthocephala) soft-bodied worm-like animals with fleshy legs (Tardigrada and Onychophora), and the slugs and snails (Mollusca).

Diversity of the system

Over a million species of terrestrial invertebrate have been described, making up 96% of known species on land. It has been estimated that at least 7 million more remain to be identified, with latest estimates suggesting that there are 8.3 million species in total [1].

Terrestrial invertebrates are adapted to life across a range of environments, from extreme temperatures towards the poles and at high elevations to tropical forests and deserts. They provide some extraordinary natural spectacles such as the migration of monarch butterflies *Danaus plexippus* or locust swarms. Other highly abundant invertebrates include the Seychelles giant millipede *Sechelleptus seychellarum* which lives on small islands of the Seychelles group, where it consumes most of the decaying vegetation, making it a keystone species in the islands' ecosystems. Many terrestrial invertebrates are bizarre in their appearance, exhibiting extreme specialised forms adapted to particular habits. For example, forms range from the burrowing mole crickets, the predatory whip-spiders and praying mantis, to specialist mimics of vegetation, such as leaf insects, stick insects and many crickets and grasshoppers. Some have remarkable biology, with the specialised grasshopper *Paulinia acuminata* living on water lilies and laying its eggs under water.

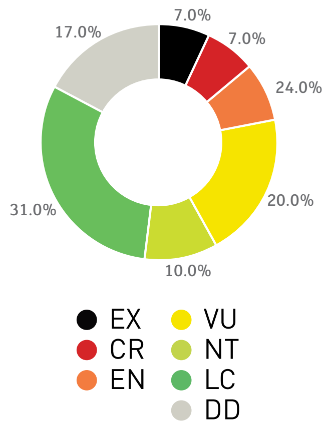
Terrestrial invertebrates cover remarkable size ranges of several orders of magnitude. Beetles, for example, range from the featherwing beetle *Scydosella musawasensis* at 0.3 mm long (comparable to a grain of sand) to species approaching the size of an adult human's hand, such as the titan beetle *Titanus giganteus* at 167 mm and the Hercules beetle *Dynastes hercules* at 175 mm.

They include particularly strange-looking animals such as the velvet worms Onychophora, soft-bodied relatives of the arthropods that catch other invertebrates by spitting glue at them. Slightly less bizarre but more dramatic is the cave glow-worm *Arachnocampa luminosa* (Diptera; Keroplatidae) of New Zealand, with four related species in Australia and Tasmania. The larvae spin silk nests on the cave ceiling and drop silken threads to trap prey (flies and moths) which are attracted to light given off by the larval glow-worm. These creatures prove so spectacular that some of the caves they inhabit, most famously the Waitomo Caves on New Zealand's North Island, have become major tourist attractions.

Status and trends of terrestrial invertebrates

Given the immense species richness of terrestrial invertebrates, it is impossible to compile a global assessment of the status of all terrestrial invertebrates. However, some families have been partially assessed or have been assessed on a geographical basis as part of regional projects. Currently the status of 3,623 terrestrial invertebrates has been assessed on the IUCN Red List, of which 42% are threatened with extinction (Figure 01). Current numbers on the Red List represent only 0.3% of described species, with a likely bias towards threatened species, and there is an urgent need to increase the assessment of invertebrates and enhance their overall representativeness in order to understand change in global biodiversity. Using the sampled approach (SRLI; [2, 3]), assessments of 1,500 randomly selected species are

Figure 01 | Global status of terrestrial invertebrates currently assessed on the IUCN Red List (3,623 species)



Giant millipede © Roberto Pedraza Ruiz

Diaea ambara © Bryce McQuillan

More than a million species of terrestrial invertebrate have been described

Spiny moss katydid (*Championica pilata*) © Michael Tweddle / Tweddlefoto.com

underway for a number of terrestrial groups (e.g. butterflies, dung beetles). At a regional scale, several initiatives are underway to assess invertebrates of particular geographical areas, for example a UK Darwin Initiative funded project to conserve the invertebrates of the island of St Helena from 2012-2015 will include assessment of their status undertaken by the St Helena National Trust and Buglife. However, more assessments still need to be planned and implemented.

National Red Lists can also be good indicators of the health of invertebrates, but may be biased towards threatened species, or those species considered to be threatened, thus underestimating levels of Least Concern species. Some countries, however, have carried out relatively comprehensive national assessments. For example, in Scandinavia overall threat levels of terrestrial invertebrates are relatively low at 10-15% [4-6]. Threat levels are much higher in the Seychelles at 29% (46% excluding Data Deficient species [7]), and reach 37 and 49% respectively in Germany and Poland (though for the latter two these may not be directly comparable [8, 9]). Very high threat levels have been recorded in North American invertebrates (51%), but this assessment is dominated by the exceptionally highly threatened Hawaiian snail fauna. Excluding this gives a threat level of 35%, which may still be biased by non-random selection of assessed groups.

In the following section, we provide a summary of the extinction risk faced by the main groups of terrestrial invertebrates. We evaluate the degree of coverage of assessments for the group, and examine what threats are most frequently found to be causing decline.

Worms and worm-like invertebrates

There are many phyla of worms and worm-like invertebrates (Platyhleminthes, Nematoda, Nemertina, and Annelida), although none of these are well represented on the IUCN Red List. They range from phyla with only a few terrestrial species described (Nemertina) to phyla comprising thousands of species (e.g., Annelida and Nematoda).

Only nine fully terrestrial species of ribbon worm (phylum Nemertina) have been described, and assessments – though partly in need of updating - show five to be Least Concern, two Near Threatened, one Vulnerable and one (*Geonemertes rodriguesensis*) Extinct.

Free-living terrestrial flatworms (phylum Platyhelminthes) have been assessed comprehensively in China (with all 14 species assessed as threatened [10]) and Seychelles (7 species, two Extinct, one Least Concern and four Data Deficient [7]). These data are too limited and imprecise to provide any meaningful indication of the status of flatworms, of which there are around 800 species in total.

The conservation status of annelid worms (phylum Annelida) has rarely been assessed, despite the obvious ecological importance of members of this group, such as earthworms, to soil systems. On the whole, the taxonomy of this group is poorly known and there is very little information on the status of the over 5,000 terrestrial species. Eight species of earthworms are on the IUCN Red List, seven of these are giant earthworms (of which six are threatened, and one Near Threatened). Of the giant earthworms, the North American giant Palouse earthworm *Driloderus americanus* was abundant in the 19th century in the Palouse prairie of Idaho, but conversion of most of the prairie to agriculture resulted in their almost complete disappearance, with a sighting in 1988 and again in 2005.

Despite their species richness (some 28,000 described species and probably at least five times as many undescribed), roundworms (phylum Nematoda) have only been assessed nationally in Seychelles where 6% are listed in threatened categories, but 62% are Data Deficient, with probably many more species still awaiting identification [7]. This group has been inadequately surveyed in many areas around the world, and very few assessments have been made for any of the many parasitic species.

While lower invertebrates are starting to feature on both global, regional and national Red Lists, by far the greatest proportion of the Red List assessments published to date are for molluscs and arthropods, the two most species-rich invertebrate phyla.

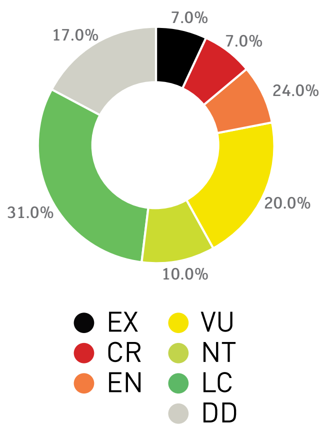
Monarch butterfly © Martin D. Parr

Molluscs

Forty percent of the 2,377 species of terrestrial molluscs currently included on the IUCN Red List are threatened with extinction (Figure 02). This figure has a regional bias, particularly towards Europe, where a regional assessment of selected European families of land snails and slugs indicates overall threat levels of around 20% [11 - see chapter 5]. National Red List data suggests that these threat levels vary across Europe, from 7% in Norway [5] to up to 42% in Germany [8]. In Seychelles, 68% of species are threatened with extinction, due to habitat alteration caused by invasive plant species and climate change resulting in drying of forest habitats and the loss of moisture sensitive species [7]. In North America, 75% of assessed mollusc species have been listed as threatened, though this is strongly influenced by the high levels of threat in Hawaiian tree snails, which are affected by invasive species. Threat levels in mainland snails are not lagging far behind, with 65% of assessed species threatened.

Terrestrial molluscs are primarily threatened by invasive alien species, residential/commercial development and agriculture. The impacts of the different threats vary geographically, for example the latter two have been specifically noted as major threats across Europe [11], whereas tropical island faunas are particularly threatened by invasive species. In Polynesia and Hawaii, the introduced carnivorous snail *Euglandina rosea* is the main (often the sole) cause of extinction of some 90 species on the Red List and probably many more.

Figure 02 | Global status of terrestrial molluscs currently assessed on the IUCN Red List (2,377 species)



Arthropods

Members of all four extant subphyla of Arthropoda [millipedes and centipedes (Myriapoda), arachnids and related species (Chelicerata), woodlice and other terrestrial crustaceans (Crustacea), and insects] are represented on the IUCN Red List. Representation varies, for example, of the 11,309 described species of millipedes and centipedes, only 31 species of South African giant millipede (genus *Doratogonus*) have been assessed as well as a single species of the class Chilopoda. Of the giant millipedes which have been assessed, 45% are listed in threatened categories (with 23% Data Deficient), due mainly to habitat loss and extremely narrow ranges.

Thirty-three species of Chelicerata (spiders and allies) are included on the Red List; less than 0.1% of the 102,248 described species. Thirty of these are spiders, of which 50% are threatened. National assessments of spiders have much greater coverage, and show levels of threat to vary widely geographically, from high levels of threat in Germany (34% [8]), Seychelles (27% [7]) and China (25%, although only a very small proportion of the fauna has been assessed [10]), to moderate levels in Norway (13% [5]) and low levels in Finland, Sweden and Denmark (3-4% [4, 6, 12]). An assessment of the 24 spider species endemic to the Iberian peninsula [13] listed 21% in threatened categories (though 71% were classified as Data Deficient).

Some species prove so spectacular that they have become major tourist attractions

While comprehensive assessments have been carried out for other groups of crustaceans inhabiting marine and freshwater systems (lobsters, crayfish and freshwater crabs), only six terrestrial crustaceans (all woodlice) have been assessed for the Red List (four Slovenian species listed as Vulnerable and two Australian species listed as Data Deficient). This represents less than 0.2% of the nearly 4,000 described species of terrestrial Crustacea. The only comprehensive assessment of terrestrial crustaceans has been carried out for the woodlice of the Seychelles where 23 of the 47 species were listed as threatened (49%, five of which are possibly extinct, not having been located since 1894 [7]). The main threats to this fauna are habitat degradation caused by invasive plants and climate change causing habitat change and sea level rise.

By far the most diverse of all the arthopods are the insects. These also include some of the most well studied of the terrestrial invertebrates. Red Listing is well advanced for some groups but the status of others is largely unknown. What is known of the status of the different insect orders is summarised below.

Orthoptera

Grasshoppers, bush-crickets and crickets are a diverse group of insects with around 25,000 described species worldwide. Many Orthoptera are flightless and therefore have very small geographic ranges which make them highly susceptible to habitat changes caused by human impacts and good indicators for sustainable land use. The most threatened species occur on tropical mountains, in rainforests and on tropical islands. Only 74

Polymita muscarum splendida © Adrián González-Guillén

Mountain spotted grasshopper (*Monistria concinna*) © Fraser Johnston

Ruby-tailed wasp (*Pseudospinoloa marqueti*) © Nick Upton / naturepl.com

species of grasshoppers and crickets are currently on the Red List, and the majority of species are listed as Vulnerable (67%). In North America, 45% of grasshoppers were assessed as threatened, although 11% of data deficiency in the fauna may overestimate threat levels. However, extinction rate in North American grasshoppers is unusually high, with 18 species recorded as possibly extinct (4%). Currently, the status of the European Orthoptera is being assessed, so that more information on the status and threats will become available in the near future.

Hymenoptera

The Hymenoptera represent a number of species of ecological importance due to their role in plant pollination - yet only 152 species of ants, bees and wasps are currently on the IUCN Red List, around 1% of the 105,000 described species. The great majority of the listed species are Vulnerable (90%). Preliminary assessments of 45 species of bumblebee [14] considered eight species (22%, or 4% of the total species number) to be threatened, and two to be Extinct. Threats are likely to include habitat loss and degradation causing severe range declines, pathogen spillover from commercial species to wild populations, competition and hybridisation with non-native commercial bumblebees, pesticides, overgrazing and climate change.

Most data on Hymenoptera currently available stem from National Red Lists, with threat levels ranging from 5% in Norway [5] to 22% in Seychelles [7]. In many cases, threat levels vary dramatically between different sub-groups. For example, 50% of larger wasps and 71% of native ants are threatened with extinction in the Seychelles [7]. Many assessments in Western Europe are restricted to certain families: ants (43% threatened in Flanders, 55% in Germany [8]), bees (34% in Ireland [15], 40% in Germany [8]) and sawflies (none threatened in Norway but 25% Data Deficient [5], 16% threatened in Germany [8]), chrysid wasps (28% in Germany [8]) and sphecid wasps (31% in Germany [8]). In North America 90% of hymenopterans are threatened, but only 55% have been assessed.

Lepidoptera

Around 180,000 species of Lepidoptera have been described, of which about 10% (18,000 species) are butterflies [16]. Butterflies are arguably the most charismatic and best known of the invertebrate groups. They make up the majority of the 720 Lepidopteran species that have been assessed on the IUCN Red List.

Declines have been observed in many regions of the world [17-19]. For example, a questionnaire survey of top butterfly conservationists in the US and Canada highlighted that the downward trend seen in range-restricted endemic species has now spilled over to include many previously more wide-ranging and common butterflies. The monarch butterfly (*Danaus plexippus*) exemplifies this as its western distinct population has declined by 80% since 1997 [18].

Regional assessments can help to shed some light on how butterflies are faring. For instance, in the US all 800 butterfly species have been assessed, with more than 17% listed as threatened [20]. In Canada, around one-third of butterfly species are believed to be at some level of risk [21]. In Europe, 8.5% of species are considered as threatened [17], with a further 10% classified as Near Threatened ([19]; see following chapter; Figure 03), due to agricultural intensification, the decline of traditional patterns of agriculture on marginal areas of land leading to abandonment of land and to the subsequent invasion of shrubs and trees and changes of woodland management.

To improve knowledge about the conservation status of butterflies globally, a sampled assessment of 1,500 species of butterflies is underway [22, 23]. So far, 846 species have been assessed, with a current geographical bias towards the Afrotropical realm. Despite extensive habitat loss and degradation in species-rich areas of tropical Africa, few extinctions have yet been documented and relatively few species (5%) are categorised as globally threatened. However, 17% of species have initially been categorised as Data Deficient, most of which appear to have small distributions and many may prove to be threatened as additional data accumulate. Furthermore, 30–50% of the endemic taxa of Madagascar, the Comoros, Principe and other Afrotropical islands are likely to be globally threatened.

Even less is known about the status of moths. North American assessments suggest higher levels of threat of Hawaiian species compared to mainland species, and differing levels of threat between families and genera, ranging from around 14% in underwing moths (Noctuidae/Erebidae) to 38% in the *Papaipema* stem borers (Noctuidae: 38%).

Coleoptera

Although nearly one in four species on the planet are beetles, at present only 189 beetle species are represented on the IUCN Red List. On national red lists, threat levels vary geographically, from 10% in Norway to 42% in Germany, and by family, due to differences in habitat associations, diets and life-histories, which may increase susceptibility to different threats. For example, in Germany, 35% of Carabid beetles (ground beetles, including tiger beetles) are listed as threatened, which is comparable to 39% of tiger beetles (Cicindellinae) in North America. Eleven percent of European saproxylic beetles have been listed in threatened categories (28% are DD) ([24] see chapter 5; Figure 04). The major threats facing saproxylic beetles in Europe are logging, agriculture and changes in fire regime.

Some species, such as dung beetles and saproxylic beetles, play important ecological roles, for example in the recycling of nutrients and the control of pest species (Figure 05). It is vital that we begin to understand their conservation status both at global and sub-global scales. At a global level, assessments are currently being finalised for a randomly selected sample of 1,500 dung beetle species as part of the Sampled Red List Index project (24.7% of the 6,060 valid, described species). Preliminary results suggest that 11% of dung beetle species are threatened with extinction. This percentage is likely to increase in future given that an additional 6% of species are known to be on trajectories toward threatened status, and the significant proportion of previously widespread species for which recent population or distribution information is unavailable. Narrow-range endemic, host-specialist, and tropical-forest inhabiting species are most threatened. Also of concern are projections that the functional consequences of dung beetle declines may be non-linear and more severe than the proportion of threatened species would suggest.

Other insects

There are many other orders contributing to the wide variety of insect species, however, many of these are less well known and often only a few species have been assessed for the IUCN Red List. As a result, none of these groups can give us a representative picture of how they are faring in the extinction crisis. For example, 2,794 species of stick and leaf insects (order Phasmida) have been described, but only two are on the Red List. Even more numerous with just short of 100,000 described species, only seven species of Diptera (true flies) have been assessed globally. Representation on national Red Lists is better, with threat levels ranging from 2% in Britain [25, 26] to 31% in Germany [8]. Similarly, some 50,000 species of bug have been described, but very few have made it onto the Red List (under 0.01%). Again, the best information comes from national assessments, but these again show a wide range of threat levels (4% in

Figure 03 | Results of the European assessment of butterflies (435 species; [19])

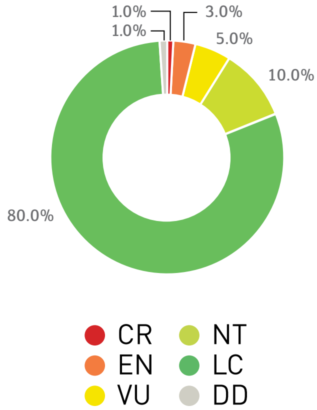
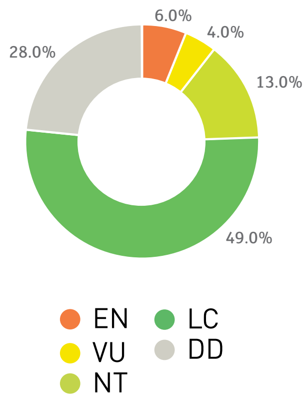


Figure 04 | Results of the European assessment of saproxylic beetles (431 species; [24])



Status assessments of the world's arthropods lag far behind the number of described species

Red milkweed beetle (*Tetraopes tetrophthalmus*) © K.P. McFarland

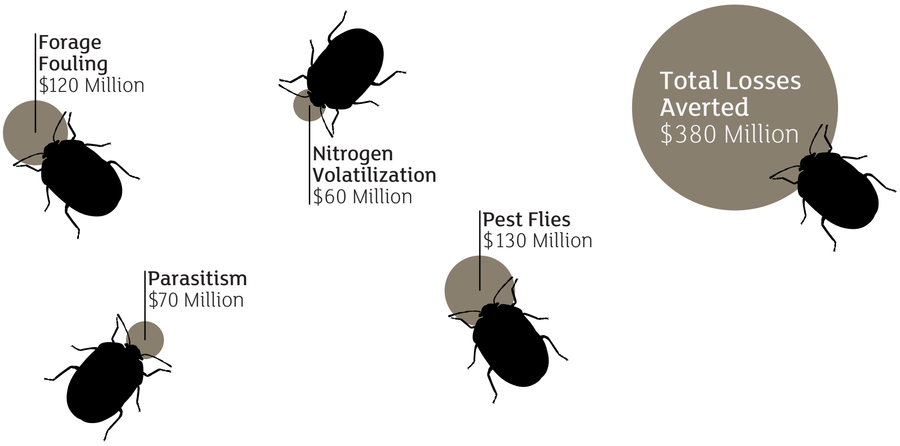


Figure 05 | Total economic losses averted annually as a result of accelerated burial of livestock faeces by dung beetles. Data from [28]

Estimated at 5 million species, insects are by far the most diverse of the arthropods

Sweden [4] to 43% in the Seychelles [7]).

Many insect orders are only represented on the Red List by a single species. Although mantids (order Mantodea) are such an attractive group, little is known about the ecology and distribution of this cryptic species group, comprising around 2,200 species. The single representative on the Red List is the Spanish species *Apteromantis aptera*, listed as Near Threatened. Another relatively numerous group, the earwigs (order Dermaptera, with around 2,000 species), is solely represented on the Red List by the Saint Helena giant earwig *Labidura herculeana* which is listed as Critically Endangered. This 8 cm long earwig was last found in the 1960s and it is highly probable that it is extinct. This is commonly attributed to predation by introduced rats and mice but may also have been due to the loss of the woodland habitat with which it was associated. The Mount St. Helens grylloblattid *Grylloblatta chirugica* (order Grylloblattaria) is listed as Vulnerable due to its restricted range and suspected declining population. All 20 species of this group are probably threatened as they are restricted to cold mountain top ecosystems which are highly sensitive to climate change. The pygmy hog sucking louse *Haematopinus oliveri* (order Anoplura) is listed as Critically Endangered as it is a specialist parasite of the Critically Endangered pygmy hog. Other similarly specialist parasites could be assessed in a similar way, but no attempt has been made at wider assessments and very little is known of the less specialist species.

Major threats to terrestrial invertebrates

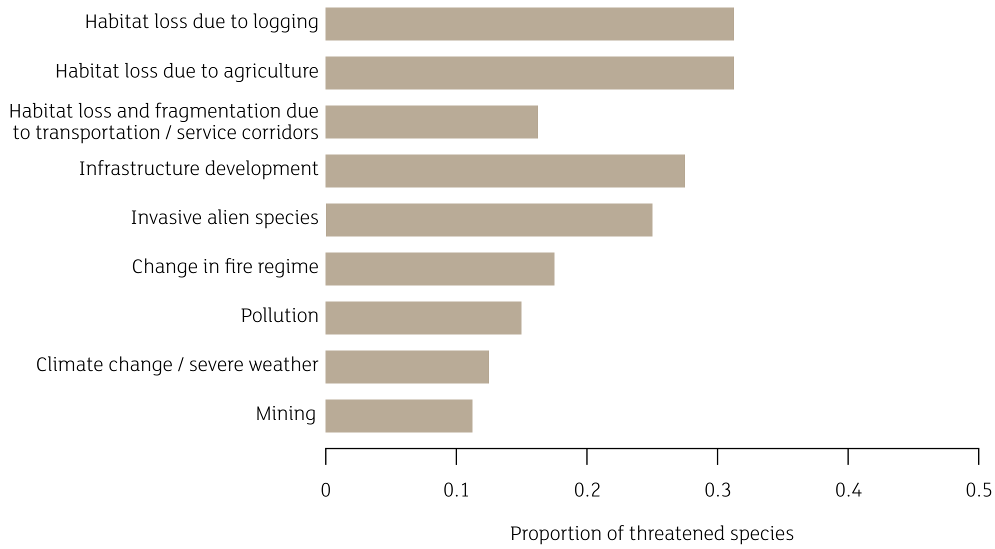
Terrestrial invertebrates are primarily threatened by agriculture and logging (both affecting 31% of threatened species; Figure 06), followed by infrastructure development (28%). Agriculture (including tree plantations) is a threat to many species due to new areas of previously natural or non-intensively managed habitat being converted to high intensity agriculture. For example, the pink velvet worm *Opisthopatus roseus* of South Africa lived in small forest patches in KwaZulu-Natal province, before many of these areas were cleared for exotic tree plantations and road construction.

Banded demoiselle (*Calopteryx splendens*) © Ben Andrew

Trapjaw ant (*Odontomachus* sp.) © Trond Larsen

Stick grasshopper © Michael Tweddle / Tweddlefoto.com

Figure 06 | Global threats to terrestrial invertebrates on the IUCN Red List. Horizontal axis shows the proportion of threatened (CR, EN, VU) species affected by each of the threatening processes. Note that species are often affected by multiple threats.



Invasive species also affect a wide range of native fauna (24%) through competition, direct predation or habitat conversion. The Endangered cloud copper butterfly *Aloeides nubilis* is mainly threatened by loss of its grassland habitat due to invasion by the tree *Acacia mearnsii*.

Although climate change has been identified as a threat to only 12% of threatened terrestrial invertebrates, the impacts of this emerging threat have only recently been investigated in many invertebrate species and the true percentage is probably considerably higher. Therefore, improved ways of diagnosing those species at high risk of extinction due to the impacts of climate change are needed [27]. In the Seychelles fauna, climate change is a contributory or major threat to many species, with the recent or imminent extinctions of several snails attributed to changes in rainfall patterns. Climate change is also implicated in the decline of the Beydaglari bush-cricket *Psorodonotus ebneri*, which is known from moist meadows in a mountain range in south-western Anatolia. Only two populations of this species have ever been recorded. It is believed that the major threat to this species is climate change, with drought having caused habitat change and eventual extinction of one of the two populations.

The importance of threats varies geographically, with invasive species affecting the greatest proportion of species in the Australasian, Neotropical and Nearctic realms, while in the Palearctic, Indomalayan and Afrotropical realms, the majority of species suffer primarily from habitat loss, caused by development, logging and agriculture respectively. The threat of invasive species in Australasia, the Neotropics and the Nearctic is due largely to the impact of invasive predatory snails on tree snails of the familiy Partulidae and a variety of invasives (trees, rats and ants) on the Galapagos Orthalicidae tree snails. Many species are threatened by several factors; in the case of the Vulnerable burrowing spider *Thrigmopoeus insignis* of India, forest habitats are being cleared for agriculture and logging, disturbed by road widening operations, fires and soil erosion. There is also a threat from capture for the pet trade.

Ecologically and economically important species

Terrestrial invertebrates include some of the most significant groups of organisms in terms of ecology, value to global and national economies, food supply and medicine. For example, the economic value of invertebrates in ecosystem services in the U.S.A. has been estimated to be considerably in excess of $60 billion a year, covering a wide range of aspects, from the major components described above to supporting bird populations which economically important in ecotourism [28].

To humans, some of the most important services of terrestrial invertebrates are pollination, soil formation and nutrient cycling. The most important pollinators are the bees. Other pollinators include the conspicuous butterflies and moths but also many fly, beetle and thrip species. Threat levels to these groups seem to vary considerably but are particularly high in the bees. This is a particular concern given our dependence on pollination and pollinators for much of our food production (Figure 07); globally insect pollination has been valued at €153 billion per year, mainly through its importance to agriculture [29].

Invertebrates such as earthworms contribute to soil formation and aeration, and transport carbon from the surface into deep soil storage [30]. Similarly, dung beetles contribute to nutrient cycling, raising soil fertility by burying dung and so transferring nutrients directly into the soil [31]. In removing dung from the surface of grazing land they also keep the grass palatable for grazing animals and reduce the problems of parasite infection in livestock and the build up of pest flies [32]; Figure 05).

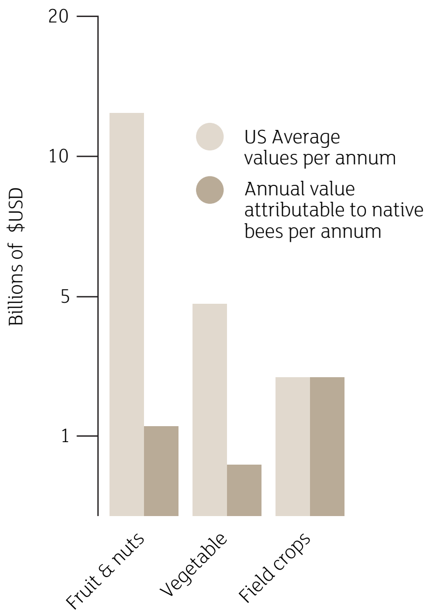


Figure 07 | Value of US crop production resulting from pollination by native insects, 2001-2003. Data from [28].

Marsh flies (Sciomyzidae) © Bryce McQuillan

Nearly one in four species on the planet are beetles

Although they are relatively inconspicuous, terrestrial invertebrates are the main herbivores in most ecosystems. Humans are acutely aware of the negative impact invertebrates can have on agricultural plant life, for example through locust swarms destroying crops and forest caterpillars affecting the growth of trees in monoculture. However, in temperate ecosystems, invertebrates may outweigh vertebrates by a factor of 10 [33] and thus are major contributors to the maintenance of healthy natural ecosystems via herbivory. For example, in savannah ecosystems, grasshoppers often represent the most important herbivores and they are important food for many threatened birds and lizards. Invertebrate groups such as assassin bugs, ground beetles, spiders, harvestmen and scorpions are major predators of other invertebrates and even small vertebrates. As a result they are regarded as important natural pest control agents and make a notable contribution to maintaining healthy agricultural systems (Figure 08).

Invertebrates also make an important contribution to direct consumption (e.g. hundreds of tonnes of mopane worms *Gonimbrasia belina* are consumed in Southern Africa, and are worth an annual $8 million to Botswana and $40 million to South Africa) and are important in an epidemiological context, most often as pest agents (directly in the case of some nematodes and lice, or as vectors of pathogens, such as mosquitoes). However, medicinal benefit arises from uses as diverse as the medicinal leech *Hirudo medicinalis* in anticoagulation and the application of blowfly maggots for necrotic tissue removal to drug identification and testing [34]. A particularly important aspect is the use of the *Drosophila* fruitflies and the roundworm *Caenorhabditis elegans* as developmental models, essential for research into a wide range of diseases and disorders.

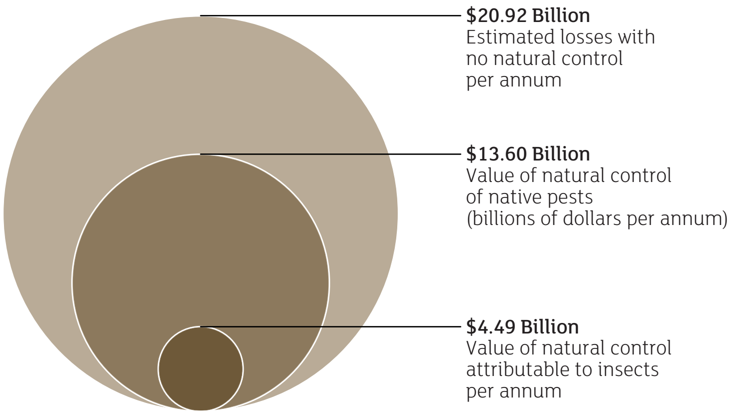
What we have lost

As many terrestrial invertebrates are small, inconspicuous or secretive in their habits, species are often overlooked, and extinctions have been under-recorded. At present 250 terrestrial invertebrates are listed as Extinct on the IUCN Red List, though this is unlikely to be a true reflection of current extinction rates. For example, many potentially extinct species have been collected very rarely (often only once) and tend to be categorised as Data Deficient on the IUCN Red List. In some cases, however, species known from single records have been classed as Extinct. For bumblebees, two of the 250 species are thought to be extinct: *Bombus rubriventris* known from a specimen collected before 1835 in the Neotropics and *B. melanopoda* from a specimen from 1878-1883 from Sumatra. In other cases, the single record may be from a specific habitat which has been lost; the Lake Pedder earthworm *Hypolimnus pedderensis* was known from only one specimen from the shores of Lake Pedder in Tasmania and this area was flooded by a hydroelectric dam in 1972. This represents the only known extinction of an earthworm species.

Identifying extinctions often relies on reasonable data to document the decline and disappearance of the species. Such data are often unavailable for terrestrial invertebrates, although there are some exceptions. The Xerces blue butterfly *Glaucopsyche xerces*, for example, was adopted by the Xerces Society for Invertebrate Conservation as symbolic of invertebrate extinction. This was the first butterfly in North America known to have become extinct due to human disturbance [35]. This butterfly formerly inhabited the sand dune systems of San Francisco until this habitat was almost entirely destroyed by urban development [35].

Regional assessments may provide reasonable records of species decline and disappearance. For example, in the Seychelles islands, intensive surveys in 1905-9 and 2000-5 provide a good indication of the level of extinction in selected species groups, with land snails and crustaceans showing the highest extinction rates (5.8% and 9.1% respectively; [7]. These data also indicate that extinction rates are highest in poorly dispersing groups

Figure 08 | Value of averted crop losses as a result of predation or parasitism of native agricultural pests by native beneficial insects. Data from [28]



(snails, woodlice and flightless insects) and lowest in those groups with high dispersal abilities (e.g. flies). Similar information on selected groups exists for other regional areas, and shows variability within and across regions. For example, mollusc extinction rate in Europe is estimated as 0.2%, though this varies from 0.5% in Sweden to 2.1% in Germany

Extinction rates are also often documented to be higher on islands: for example, the proportion of extinct mollusc species in mainland North America lies between 0.1-0.5%, though in the Hawaiian islands this is considerably higher at around 70%. This is due to a combination of factors, with particular sensitivity of some island tree snail radiations in the face of introduced specialist snail predators. Data on regional invertebrate extinctions suggest an extinction rate in the region of 0.8-3.5% on continents and at least ten times higher rates on islands, compared to overall extinction rates in vertebrates of currently 1.1%. It is therefore possible that invertebrates may in fact face a significantly higher extinction risk than vertebrates.

Blister beetles (*Mylabris quadripunctata*) © Nick Upton / naturepl.com

Some of the better-known terrestrial invertebrate extinctions are those of large species such as the St Helena giant ground beetle *Aplothorax burchelli* which has not been recorded since 1967. Probably the most conspicuous loss of all was the Rocky Mountain locust *Melanoplus spretus* which was last seen in 1902. Until 1877 it was one of the most abundant animals ever recorded, with swarms reported to cover up to 513,000 km^2 and including some 12.5 trillion insects. Other species are harder to detect and it is therefore difficult to confidently establish extinctions (e.g. the North American cranefly *Triaenodes phalacris*, the robberfly *Cophura hurdi*, the sallfly *Alloperla roberti* and the Hawaiian fruitfly *Drosophila lanaiensis*).

The ability of invertebrates to survive in very small localities does mean that some apparently extinct species can be rediscovered unexpectedly. The Lord Howe Island stick-insect *Dryococelus australis* was thought to have become extinct around 1920 due to predation by introduced rats. However, it was rediscovered on a small islet off the main island in 2001 and is now considered to be Critically Endangered.

Conservation successes

There are several good examples of how conservation action can lead to effective action for species at risk. The mardon skipper (*Polites mardon*), a small brown butterfly restricted to meadows in northern California and Washington, has been the focus of successful conservation action. This species faces a variety of threats that have probably contributed to its decline, including loss of prairie and meadow habitats, grazing by domestic livestock, conifer, shrub, and grass encroachment, off road vehicle use of meadows, applications of insect-killing bacteria, climate change, and issues related to small population size and stochastic events [36]. The Mardon Skipper Work Group was formed in 2005 to identify the conservation needs of the species. This group was a collaboration between the U.S. Forest Service, Bureau of Land Management, U.S. Fish and Wildlife Service, Washington Department of Fish and Wildlife and the Xerces Society for Invertebrate Conservation.

The group located several previously unknown locations for the species and determined the management needs of each population. This included developing management plans for protection and habitat restoration at key sites. Management activities included exclusion of off-road vehicles, management of grazing using fencing, control of encroaching trees and invasive plants, and increased protection for the populations. The threat status of the species on the U.S. Fish and Wildlife Service listing priority has now been reduced from 3 to 8, as a result of the action taken to make its future more secure.

In some parts of northwestern Europe, active conservation measures for the field cricket (*Gryllus campestris*) have been implemented to reverse the decline of this species which is threatened by habitat loss caused by changes in agricultural practices. The re-introduction of captive bred individuals in England was very successful and habitat management for this species led to an enormous increase in the size of a population in northern Germany (from 32 to nearly 3,000 singing males).

In southern France, the Crau steppe grasshopper *Prionotropis hystrix rhodanica* is endemic to a small steppe area near Marseilles. The Crau is a unique stone steppe which has traditionally been grazed by sheep. Grazing is still managed in the reserve but this is fragmented and parts of the reserve are owned by the French army which is planning to construct buildings on one of the main populations of the grasshopper. Being restricted to just a few small parts of this area, the Crau steppe grasshopper is a flagship species for the Crau conservation project which is undertaking research to minimize the loss of habitat which is likely to result from construction plans of the French army.

Praying mantis © Madjid Momeni Moghaddam

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Dung fly © Patrik Katona

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Developing invertebrate conservation - challenges and opportunities

Chapter 5
Invertebrates: our natural capital

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Introduction
Invertebrates provide a bewildering array of goods and services to the people and economies of the world. They are an integral, yet much ignored part of our natural capital (Box 01). Invertebrate conservation must succeed in the face of many challenges; not least that scientific knowledge about invertebrates, although substantial and useful for certain groups, is far less prevalent than that of other groups such as vertebrates [1]. Contemporary conservation strategies are primarily designed around conserving vertebrates, and there is very little general consensus as to how those strategies might also act to conserve invertebrates. However, as recognition builds of the pivotal role that invertebrates play in providing structure, function and services through the ecosystems that they are part of, invertebrate specific conservation strategies will have to be developed.

Previous chapters in this report have demonstrated that a large proportion of diverse invertebrate groups are already threatened with extinction, in freshwater [2], marine [3] and terrestrial systems [4]. With human pressures on these systems becoming wider spread and intensifying in many cases [5-6], one of the key questions that national governments must face is, how will the benefits that humans derive from these systems be affected by invertebrate decline, and what is at stake if these impacts are allowed to continue?

The answer is not straightforward, but given the diversity, abundance and range of invertebrates, there is little doubt that continued loss of invertebrate fauna would be highly detrimental. There are two related concepts which can provide answers in the short to medium term. The first is that the natural capital conferred by invertebrates in its many forms, must be recognized and measured. Past studies suggest that on the whole, national level evaluation of status and trends of invertebrate groups lags far behind that of vertebrates and plants [7]. We evaluate the extent to which this has changed globally, and focus on Europe for regional and national examples. Understanding change in the status of natural capital is a key first step to enabling biodiversity information on invertebrates to be integrated into societal decisions.

The second concerns limits to human growth. Clearly growth in population and resource consumption cannot continue indefinitely in a finite world. Yet over recent decades, the vast majority of evidence indicates continuing growth, often at close to exponential rates in both population and consumption [8]. Whether we are borrowing from the future [9], or using resources that are far from their limits, or are adapting creatively through innovation and technologically driven efficiency and replacement [10] remain difficult questions to answer in certain cases. Many believe though, that we are actually failing to act responsibly given evidence that certain limits are dangerously close, or even are already transgressed [11].

In this chapter, we highlight some of the critical roles that invertebrates play in providing goods and ecological services to humans. We then evaluate ways in which natural capital might be measured. We appraise, using a regional case study in Europe, how trends in the status of invertebrates might be used to infer change in the biotic component of natural capital. Finally, we review how well National Biodiversity Strategies and Action Plans and National Red Lists incorporate invertebrate biological data, and examine how a lack of baseline data might compromise our ability to integrate invertebrates into national green accounting, and natural capital calculations in the future.

Box 01 | What is natural capital?
Natural capital is the stock of ecological wealth or environmental assets that sustains human well-being. In its various forms – species, habitats and ecosystems - natural capital describes the ecological resources that humans need to survive. We are probably more familiar with using the word ‘capital’ in a financial context to describe a stock of wealth, like a savings account or a valuable asset. Although ecosystems and the biological diversity within them are well defined concepts, referring to them in more economic terms is a more recent approach. Just as financial capital in a savings account generates additional wealth as interest, natural capital describes the physical assets that generate a vast array of benefits to humankind in the form of ecosystem services.

Ecosystem services, derived directly from natural capital, are the renewable flows of materials, energy and processes that we use, need and benefit from, for example the production of food or fuel, pollination, water purification, nutrient cycling and climate regulation. Since these ecological processes would not arise if it were not for the existence of, and interactions between, biodiversity and natural resources, ecosystem services can be considered as the ‘dividends’ of natural capital [46].

Given that biodiversity, natural resources and ecosystem services are so closely linked, the term ‘natural capital’ is often used to define them all together. As we realize the huge extent to which humans rely upon the services that ecosystems provide, a greater awareness of the importance of maintaining the natural capital or ‘stock’ that produces them, is necessary. By distinguishing the natural capital stock from the ecosystem service dividends, we can more clearly measure, monitor and appreciate these critical components to human well being.


Dung beetle (*Onthophagus* sp.) © Trond Larsen

White-tailed bumblebee (*Bombus lucorum*) © Nick Upton / 2020 VISION / naturepl.com

Provision of vital goods and ecological services by invertebrates

Invertebrates are key components of fully functioning ecosystems and therefore have a high value to human societies. Without their presence, the amazing number of ecological functions they carry out would be compromised, and life on earth would be very different from what we know.

The vast diversity of life forms included in this group show incredibly different body plans and physiological abilities; from sea sponges, to coral polyps, to molluscs, to spiders and insects. This variety of designs allows these animals to occupy a vast number of ecological niches and contribute to maintain ecosystems' balances and functions while they feed, move and reproduce.

Human beings benefit from the existence and activity of invertebrates in a number of ways, some of which we highlight below. Invertebrates are hugely important (frequently essential) to many economic activities and provide very important services to human populations. In the following sections, we detail how some of these ecological services work, and the importance of invertebrates to delivering these services for human wellbeing.

Bumblebee © Bryce McQuillan

Egyptian locust (*Anacridium aegyptium*) © George J. Reclos

Pollination by animals is mainly carried out by insects

Invertebrates are essential to the functioning of terrestrial ecosystems. Large numbers of plants rely on organisms like bees, bumblebees, wasps, flies, butterflies, beetles, moths, thrips and other invertebrates to reproduce and complete their life cycle through pollination. This highly important ecological function is not only vital for plants and other organisms dependent on them, it is also crucial for human society, as many agricultural crops depend on pollinators to produce the fruits and the seeds that we consume.

The Food and Agriculture Organization of the United Nations (FAO) estimates that globally, around a third of agricultural crops rely on pollination carried out by insects and other animals. Moreover, they estimate that wild bees are responsible for the pollination of 71 of the 100 crop species that provide 90% of the food supply to humans in 146 countries [12].

In the European Union (EU) for example, around 84% of the crops and 80% of the wildflowers rely on insect pollination. The contribution of these to the global economy has been estimated to be around €153 billion, which represents approximately 9% of the value of agricultural production. Furthermore, the disappearance of pollinators would translate into a consumer surplus loss estimated between €190 and €310 billion [13].

Soil nutrient recycling, dung burial and waste disposal

Animals such as woodlice, ants, springtails, earthworms, spiders, cockchafer larvae, land-snails, slugs, crickets, beetles and many others help to maintain good quality soil. By their movement and their feeding activities they contribute to physical decomposition, burial and distribution of organic matter coming from dead animals and plants and feces into the soil. As part of the nutrient cycle, they make these waste materials available for decomposers (particularly fungi and bacteria), which subsequently release inorganic nutrients into the soil, making them available for uptake by plants. These ecological functions provide valuable ecosystem services such as soil fertilization.

Such cycling of nutrients is worth a significant amount to national economies. For example, one American study from 1997 estimated the global economic value of soil biodiversity at USD $1,500 billion per year [14]. A study in Ireland calculated the value of soil fertility and of nutritive elements cycling at €1 billion per year. Finally, in France, the carbon stock present in grassland soils has been valued as €320 per hectare per year [15]. Clearly the cost of providing such services, should the species responsible for them decline, would be prohibitively large for many national economies.

Water filtration

In aquatic environments many invertebrates (e.g. shrimp, krill, crabs, bivalves, sponges, and cnidarians) play a definitive role on nutrient cycling, water purification and even pollutant removal. By filtering water to feed on suspended matter and food particles, they remove sediment, nutrients, algae, bacteria, etc that in excess can cause problems in aquatic ecosystem balances.

For example, it is estimated that a single

Afrithelphusa monodosa © Neil Cumberlidge

Invertebrates provide a bewildering array of goods and services to the people and economies of the world

oyster can filter up to 124 litres of water in 24 hours, yet 85% of oyster reefs have been lost globally, and they are considered functionally extinct in 37% of estuaries and 28% of ecoregions [16]. A single unionid freshwater mussel, the dominant filter feeders in many of the world's lakes and rivers [17] can filter about 40 litres of water per day [18]. Such filtering helps to maintain water clarity and encourages establishment of macrophytes [19]. A marine sponge can pump a volume of water up to 10,000 times its own size in one day and the crustacean *Daphnia magna* (measuring up to 5 mm) has a filtration capacity of 80 ml each 24 hours.

Fertilizer runoff from agricultural systems can overwhelm waterways. A healthy ecosystem helps to filter out these excess nitrates. Removing this excess nitrogen from water helps limit phytoplankton growth rates - biomass that would otherwise hinder light penetration, and limit growth of natural submerged aquatic vegetation. The problem is significant in both inland waterways and coastal systems. The loss of a considerable part of the sea grass beds that serve as important nurseries for many coastal fish species can be particularly detrimental. Kahn & Kemp [20] determined that a 20% reduction in total submerged aquatic species in the Chesepeake Bay, in the United States, resulted in an annual loss of $1-4 million in fisheries value.

Components of food chains and a food source for humans

In a functional sense, invertebrates are essential in the food chains of most aquatic and terrestrial communities. They comprise a wide variety of life forms and habits, and therefore play roles at all levels of the food chain, including as herbivores, carnivores or decomposers. In marine habitats, birds, fish, mammals and even other invertebrates rely on these largely dominant organisms for food.

Invertebrates both support many of the economically important vertebrate species for humans and are themselves an important source of food for human populations. In the marine realm, some of these animals, for example crabs, shrimps, mussels, oysters and squids, have great economic value and represent an important source of income for many countries. Terrestrial molluscs, particularly those from the family Helicidae, are widely eaten in the Mediterranean region, where species like *Helix pomatia* and its relatives are farmed and widely commercialized on the local markets.

FAO estimated that during 2009, the global export of frozen shrimp was 1,718,954 tonnes, which was valued at an amount of nearly ten billion USD [21]. A country like Indonesia for example exported 6,520 tonnes of jellyfish during that same year, which represented an income of $11,933,000 for this nation [22].

Invertebrate products

The direct use of invertebrate products by humans is not limited to consumption as food. Many invertebrates also provide materials and compounds that are useful to humans, such as fibers, dyes, mineral materials and substances for medical use. Some of these products, such as the shells of the marine bivalve *Spondylus princeps*, which ranges from Panama to northwestern Peru, have acquired a great cultural importance. This mollusc was of great ornamental, ritualistic and economic importance to pre-Columbian Andean civilizations, and even served as currency.

In other regions like Europe, marine molluscs such as *Murex* sp. and *Conus* sp. also tend to be highly valued for their ornate shells, as well as the shell-meat (mussels, oysters, razor shells). Some species have long had a cultural as well as commercial interest. For

Araneus sp. © Michael Tweddle / Tweddlefoto.com

Southern Wartbiter (*Decticus verrucivorus*) © George J. Reclos

Box 02 | National green accounting

Economic prosperity can only stem from sustainable economic growth. There is strong emerging evidence which demonstrates that a healthy environment is essential to long-term economic growth. The economic benefits of protecting biodiversity and ecosystems greatly outweigh the costs of doing so. For example, the recent Economics of Ecosystems and Biodiversity study showed that protected natural areas can deliver economic returns that are up to 100 times greater than the cost of their protection and maintenance [46].

Costing services has always been problematic [47], but at present, very few of the ecosystem services humans derive from the natural world have a financial value in the marketplace, while the majority, which are equally vital to continued wellbeing, do not. Society places a much higher economic value on commodities such as food and fuel than on other services that are equally essential for economic stability and human wellbeing, such as climate regulation, flood control, and water purification. This leads to an imbalance in the way that decisions are made about how to use the natural environment. Putting natural capital at the heart of a green economy is an essential step for the world's governments.

Wasp spider (*Argiope bruennichi*) © Marco Bertolini

example, animals from various species from the family Muricidae were used to produce blue and purple dyes for clothes, including Roman Emperors' robes.

Marine snails from the family Conidae proved to be very interesting for the pharmaceutical industry. Some of the species are excellent fish hunters, but still slow moving snails. This group of snails developed an intriguing array of short chain peptides that block ion-channels and/or receptor cells of neurotransmitters immobilizing the prey. Today, first products based on conotoxins reached the market and are used as extremely powerful narcotica.

Furthermore, the use of the silk worm (*Bombix mori*) to produce silk, of many species of marine sponges to make fibers for cleaning and other purposes, and the use of molluscs such as the sea snail *Plicopurpura pansa* for obtaining dyes for textile products, are only some of the near infinite number of the provisioning services provided by invertebrates to humans.

Fighting agricultural pests

The use of invertebrates for pest control in agriculture as an alternative to the application of phytosanitary chemical products has become very widespread over the past several decades. The use of populations of natural enemies (in several roles, including as predators, parasites, parasitoids, pathogenic agents) to fight pests and reduce their population size, therefore reducing or avoiding the damage they cause to crops, has become increasingly prevalent as more is learned about the potential of bio-control.

Climate change is the fastest growing threat to European invertebrates

Some of the most commonly used organisms in this type of crop protection are insects and mites. A well known example is *Trichogramma* wasps, which are used against the corn borer (*Ostrinia nubilalis*), whose larvae attack and cause serious damages to corn crops. *Trichogramma* wasps are a parasitoid of the corn borer. They lay their eggs on corn borer eggs, where the wasp larvae develop, killing the corn borers in the eggs.

The use of invertebrates to fight agricultural pests has shown to have considerable economical benefits in the long term since it allows saving costs in pesticides. For example, in one of the biggest citrus producing states of Zimbabwe, 50% of the costs of fighting red scale (*Aonidiella aurantii*) were saved between 1979 and 1980, by changing the application of wide spectrum insecticides for a biological control programme. In New Zealand, the introduction of a parasitic wasp to fight the army worm (*Mythimma separate*) helped save $500,000 on insecticides between 1974 and 1975 [23]. Furthermore, a study carried out by the University of California estimated that each dollar spent for biological control on the importation of natural enemies, their massive-scale breeding and release, has resulted in 2,500% of benefits through the prevention of the reduction of the quantity and the quality of the crops, and in the reduction of the costs of pest control [24].

Measuring natural capital

So why are humans not protecting our natural capital if we obviously value it in so many different ways? Although we could not survive without natural capital and its ecosystem services, the components are very rarely bought, sold or rented and often have no tradable price, though they clearly contribute to the economic value of the products we produce and the continued wellbeing of our society. This obstacle has been referred to as the 'economic invisibility of nature'. Since we do not physically pay for the vast majority of components of natural capital or ecosystem services, these elements do not have a recognised place in our global or national economies. Without integrating essential natural capital into our economic mechanisms in some more tangible way (see Box 02), there is no apparent cost to depleting these stocks and it is likely that they will continue to be lost.

While putting a monetary value on all aspects of biodiversity is not a desirable outcome, a key step which must be taken in order to understand the impact of change in the status of natural capital is to measure and monitor its components, trying to understand its value, in all ways in which this might be measured, to society. One of the most intriguing possibilities at a national and regional level is to use national and regional Red Lists in order to track an important measure of the biotic component of natural capital; the health of species. Species and their interactions provide the basis from which natural capital is derived.

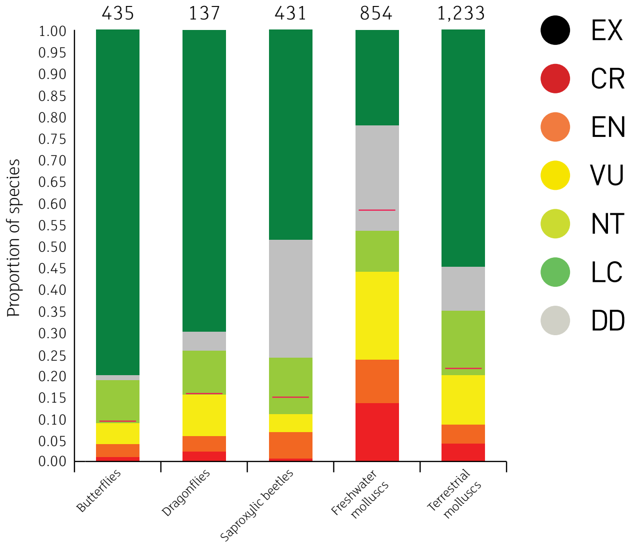
In France, the carbon stock present in grassland soils has been valued in €320 per hectare per year

Red Listing provides a means to gauge the relative health of species, from which we can derive measures to infer change in the status of natural capital. Red Listing is a process which has been carried out by many nations. Below, we draw on a European case study, and show how it can be used to inform regional and national level environmental policy decisions. We conduct a gap analysisof how invertebrate national Red Lists might be used to inform governments about change in important components of natural capital.

Case study: assessing risk of extinction for invertebrates in Europe

Europe is a very diverse continent in species and habitats as well as culture and states. Many European countries are rather small in size and in order to adequately conserve

Figure 01 | Overview of the Red List Categories for each of the invertebrate groups assessed in Europe. Species are considered threatened if they fall in the categories Critically Endangered (CR), Endangered (EN) or Vulnerable (VU). The red bar shows the most likely percentage of threat assuming that species identified as Data Deficient (DD) show an equivalent proportion of threat as the species with sufficient information for an assessment. For simplicity, EX includes Extinct as well as Regionally Extinct species in this graph.



44% of European freshwater molluscs are threatened with extinction

species and address the plight of those with high extinction risk, cooperation at a regional level is required. The European Union is a unique and unparalleled union, comprising 27 member countries that agreed to streamline their policies for the greater benefit. In this environment, a Europe wide Red List proves an effective tool for informing and performing species conservation.

In 2008, the first European Red List of Europe's mammals was published [25]. Since then, nearly 6,000 species from many different taxa have been assessed (www.iucnredlist.org/initiatives/europe/publications). Species experts from all European countries collaborated to compile information on the distribution, population size and trends, ecology and habitats, use and trade, major threats, and conservation measures in place and needed for the species throughout their whole European range. Based on this information, the IUCN Red List Categories and Criteria at regional level [26] were applied and the risk of extinction evaluated, for the whole European region as well as for the subset of the 27 EU Member States. Factsheets for each species were published online on the European Red List (www.iucnredlist.org/Europe). The wide range of information contained in the factsheets provides guidance for the appropriate conservation measures necessary to help safeguard each species. This information provides a baseline from which to measure change in natural capital, and contributes to setting priorities for species conservation at national and European level.

Invertebrates on the European Red List

Among the 6,000 species assessed to date, a total of 3,090 are invertebrate species of which 71.6% (2,212 species) are endemic to Europe. The invertebrate groups assessed comprise:

- all European butterflies (435 species)
- all European dragonflies (137 species)
- selected saproxylic beetles (431 species)
- all freshwater molluscs (854 species)
- selected terrestrial molluscs (1,233 species)

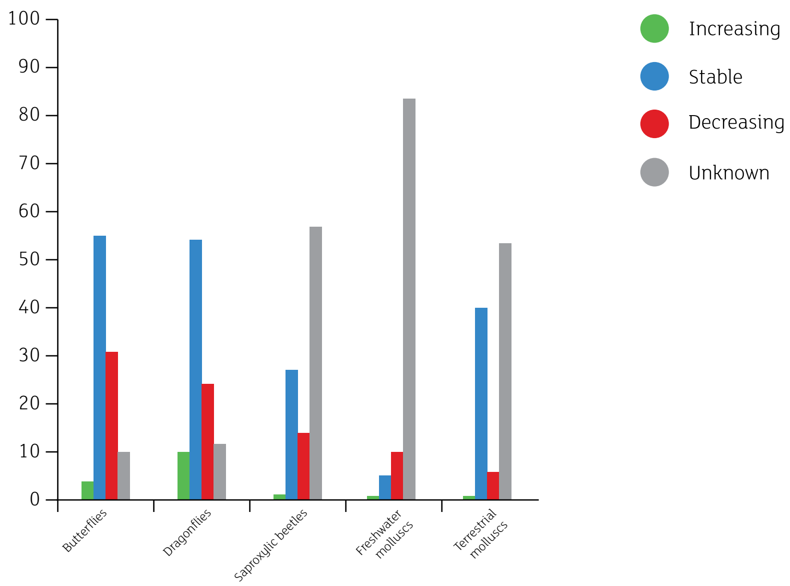
Whereas it was feasible to assess all European butterflies, dragonflies and freshwater molluscs, as a dedicated network of experts was already established and as the overall number of species was manageable in a project time frame, it was not possible to assess all species in the other two invertebrate groups (saproxylic beetles and terrestrial molluscs). In Europe, there are *c.* 2,700 terrestrial molluscs listed of which two superfamilies (Helicoidea and Pupillioidea) were prioritized, as they include many of the species listed in European Union nature legislation (around half of Europe's terrestrial mollusc species; [27]). All species of saproxylic beetle families and subfamilies protected by EU nature legislation, as well as two families dependent on old-growth (Elateridae and Cetoniidae) were selected (around 17% of the European saproxylic beetle fauna; [28]).

Figure 01 compares the levels of threat between the different invertebrate groups assessed for Europe. Freshwater molluscs are the most in peril with 58% of all species threatened with extinction [27]. In comparison, 9% of butterflies, 15% of saproxylic beetles, 16% of dragonflies and 22% of terrestrial molluscs are threatened [27-30]. The percentage of species assessed as Data Deficient is very high among saproxylic beetles (28%) and freshwater molluscs (25%) and considerably lower for the well known butterfly and dragonfly species (1% and 4% respectively).

The lack of knowledge for the two mollusc groups and the saproxylic beetles is also demonstrated in the overall population trend of species (Figure 02). For 83% of freshwater molluscs, 57% of saproxylic beetles and 53% of terrestrial molluscs, the population trend is unknown [27-28]. One third of butterfly and one quarter of dragonfly species have populations that are declining whereas for both more than half of the populations are stable [29-30].

However, it is important to note that the number of invertebrate species assessed so far by the European Red List represents only a small fraction of the total number of invertebrate animals in Europe. Even very well known groups, like spiders (*c.* 4,000 species in Europe), have not yet been addressed.

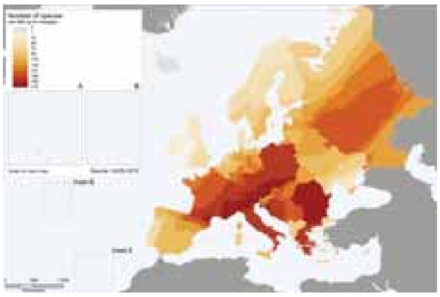
Figure 02 | Population trends for species in each of the European invertebrate groups.

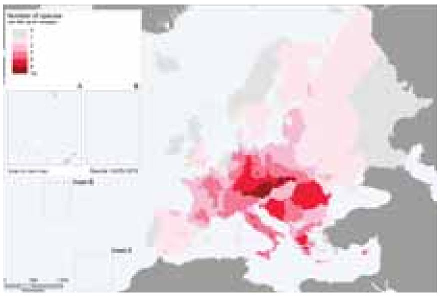


Honey bee (*Apis melifera*) © Michael Tweddle / Tweddlefoto.com

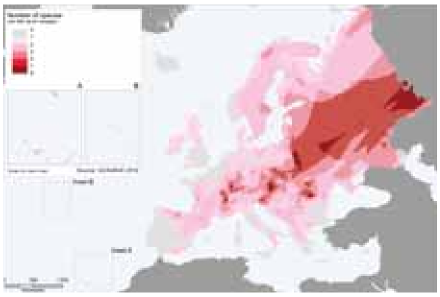
Figure 03 | Distribution patterns of each of the European invertebrate groups.

Figure 04 | Distribution of threatened European invertebrate groups

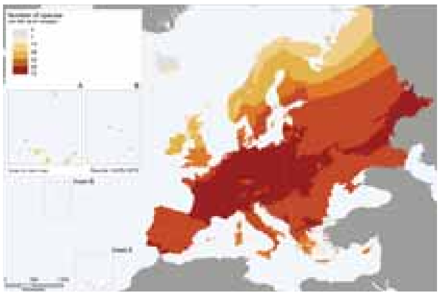




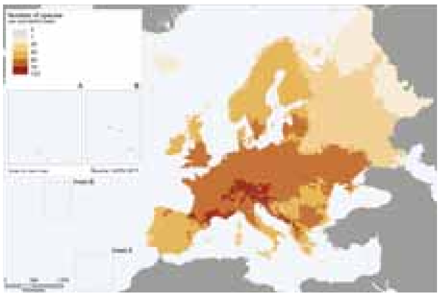
Beetles



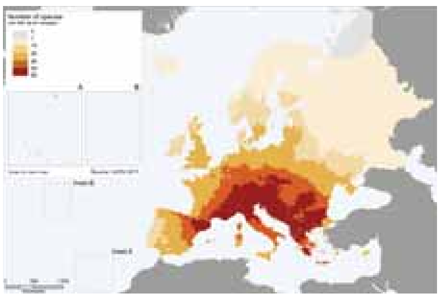
Butterflies



Dragonflies



Freshwater molluscs



Terrestrial molluscs

Centres of invertebrate diversity

Figure 03 shows the centres of species diversity for the five invertebrate groups. The highest species richness in butterflies is in mountainous areas of southern Europe including the Pyrenees, Cantabrian mountains, Alps, Dinaric Alps, Appenines, Carpathians and the Balkan mountains. The richness of endemic species follows a very similar pattern with the Pyrenees and the Alps demonstrating high concentrations of endemic species [29]. Dragonflies are most species rich in the southern part of Central Europe where Mediterranean and species from temperate climates co-exist although the highest diversity of endemics and near endemics is centred in the Mediterranean itself [30]. Saproxylic beetles show a similar pattern with centres of richness in Central and southern Europe as well as on the Balkan Peninsula [28]. For both freshwater and terrestrial molluscs, the highest species richness is found in the Mediterranean region, in particular in limestone areas. The Mediterranean and Macaronesian Islands represent a high number of endemic terrestrial molluscs [27]. Overall, invertebrate species richness and rate of endemism are lowest in the northern fringes of Europe and highest in the Alps, Pyrenees and the Balkans as well as in the Mediterranean region and on the Macaronesian islands.

These diverse centres of diversity and threatened species richness across these different invertebrate groups in Europe, demonstrate how fundamentally important the monitoring of a range of invertebrate groups is, to ensuring that natural capital is adequately monitored and accounted for. The range of invertebrates evaluated here has unique roles in supporting and providing many of the services which the human population of Europe relies on and benefits from.

Major threats to invertebrates

Species in Europe suffer generally from a combination of threats with often cumulative effects. Although certain threats are specific to certain invertebrate groups, there are two that affect all five groups. First, the expansion of agriculture or urban areas and the subsequent loss or deterioration of habitat. The rate of land-take and soil-sealing in the European Union is 920 km² per year and although this number is slowly decreasing [31], it is still a considerable amount of habitat lost for the species. The second most common threat is climate change; effects are felt by species in several different ways. Saproxylic beetles, for example, depend on tree species as their habitat and it is therefore difficult to predict the mobility of those beetles in the face of a changing climate [28]. It is thought that the northward range shift of trees, tracking a warming climate in Europe, could lag behind that of other species, making the mobility of commensal species of beetle somewhat unpredictable.

Butterflies depend on the availability of their food plants in the right habitats and their ability to locate them, which depends on their mobility and the connectivity of the landscape. Some species are highly mobile and can be found all over the continent, where others are extremely sedentary and hardly ever leave the patch where they pupated.

These species often have a very patchy and local distribution [29]. The observed and predicted increased frequency and intensity of droughts affect freshwater molluscs and dragonflies [27,30].

Dragonflies are freshwater dependent species and therefore the alteration of their habitat due to dams and water management such as canalization of rivers, water pollution and droughts are the main causes of population declines. Those factors led to particularly severe declines and extinctions in western Europe from the 1960s to 1980s. However, a decrease in eutrophication and improved water management led to a general recovery of species of running water since the 1990s. More recently species of mesotrophic habitats such as fens and bogs are also increasing in western Europe showing the positive impact of improved environmental legislation. The Mediterranean region on the other hand still hosts most of the threatened species (Figure 04). This is due to a higher number of restricted range species and an increasing demand for water for irrigation and consumption combined with increased drought events [30].

Freshwater molluscs face different threats depending on their habitats and life-cycle. The larger freshwater bivalves (family Unionidae) have longer generation times and are more threatened than the smaller pea-clams (family Sphaeriidae), mainly by continued decline in water quality, especially eutrophication, as well as loss of their fish hosts and increasing threats from non-native bivalves which are expanding in Europe. This has implications for the loss of ecosystem services they provide in large water bodies (rivers and lakes; [2]). The most threatened groups are the various families of freshwater gastropods that are resident in springs and groundwater sources. The highest numbers of threatened spring-snail species are found in central Europe and the Mediterranean region (Figure 04) where the main threats are overabstraction of water for a variety of purposes (e.g. irrigation for agricultural crops, domestic supplies), as well as continued decline in water quality, caused by sewage, pesticides and fertilizers. The extraction of water does not only affect species by a reduced availability of water but also by "cleaning" springs by removing fringing vegetation and then concreting the base of pools [27].

A single oyster can filter up to 124 litres of water in 24 hours; a global loss of 85% of oyster reefs compromises this free water filtration service

Nettle weevil (*Phyllobius pomaceus*) © Alex Berryman

Saproxylic beetles are dependent on aging and wood decay processes in trees – logging and wood harvesting are the biggest threat subject to commercial forestry, hand in hand with the loss of veteran trees and the lack of new generations of trees that will become the veterans of the future. This is a threat in non-intervention forests as well as in the wider countryside and in urban areas, which all support rare and threatened saproxylic beetles. Old trees and dead branches are often removed for safety reasons or for sanitation and forest hygiene. The highest concentration of threatened saproxylic beetles is in central and eastern Europe as well as the Italian Peninsula, Greece and Cyprus (Figure 04; [28]).

Butterflies are excellent indicators of ecosystem modifications as they have specific food and habitat requirements for different life cycle stages and are sensitive to change. More than half of Europe's butterflies are dependent on grassland and it is not surprising that the biggest threat is agricultural intensification including an increase in livestock, drainage of wetlands, conversion of grassland into crop land and changes to the intensity of management. On the other hand, the abandonment of traditional management practices leads to the succession of shrubs and trees, changing the grassland habitat composition and therefore impacting Europe's butterflies. Concentrations of threatened butterflies can be found in central and eastern Europe (Figure 04; [29]).

Terrestrial molluscs show the highest concentration of threatened species on the Macaronesian Islands due to a combination of a high volume of restricted range endemics and increasing pressures from urbanization and tourism. Their isolation in deep-sided valleys allowed evolution of closely related species since their presence in the Tertiary. Greece, as a country including many small islands, has one of the highest species diversity and endemism in the European region, and hence also the highest number of threatened mollusc species (Figure 04). Urbanisation and tourism development (including recreational activities) are also two of the most significant threats to terrestrial molluscs overall. Similar to the butterfly species, an increase in the intensity of grazing but also the lack of grazing negatively affects some species of land snails. Wildfires, although a natural part of the Mediterranean ecosystem, can be disastrous for terrestrial molluscs when these fires increase in intensity and longevity due to changed fire management strategies [27].

Conservation action recommendations

As Europe's invertebrates suffer from a combination of threats, a combination of conservation actions are required to secure the future of those species. For some species, protection is provided under the EU nature legislation and/or the Bern Convention, but not all. For other threatened species, in particular for the underrepresented groups of saproxylic beetles and molluscs, no legislation is apparent. The EU Groundwater Directive and the Water Framework Directive are of particular importance to freshwater dependent species as they are expected to benefit freshwater biodiversity by addressing issues such as over-abstraction and water quality.

The protection of key habitats is an important conservation measure and can take place at various levels, ranging from micro-habitats such as a tree to whole landscapes or river/lake catchments. For butterflies, priority sites (termed Prime Butterfly Areas) have been identified and could be afforded greater protection if included in the Natura 2000 network in the European Union [29]. Action plans for single species or their habitats are recommended for most threatened species. This includes, for example, actions to ensure the continuity of traditional management systems in semi-natural areas for butterfly species [29] or a freshwater conservation plan for endemic dragonflies on Crete [30]. Plans to address specific threats such as water abstraction are important and often require cross-border cooperation. At some sites, there are numerous threatened species, so a multi-species approach, which manages the location with sensitivity to all the requirements of the threatened species, would be a benefit.

Conservation of invertebrate species often lags behind those species which are considered more charismatic or appealing to humans (Figure 05). Raising awareness of invertebrates and of the knock on effects their decline could have on humans is of major importance for long-term conservation. While the more charismatic species of butterflies and dragonflies are already well perceived by the public, thereis little awareness about the requirements of other groups such as molluscs and saproxylic beetles.

In the short-term, monitoring programmes should be established for threatened and Data Deficient species in order to establish their population size, distribution and trends. Only with improved knowledge will conservation status of species improve. This will furthermore improve the use of those species as indicators for environmental changes but will also help us to understand the best conservation measures working. For example, 15 countries in Europe have established a butterfly monitoring scheme which follows trends of butterflies nd feeds into the European Grassland Butterfly Indicator. Extending those existing schemes to cover more countries would result in a better understanding of their status across Europe [32].

A priority for the European Red List is to assess the extinction risk of further groups of invertebrates. IUCN is currently working on assessments for all European bees (c. 2,000 species) in collaboration with the STEP project [33] and a wide network of bee experts. The results of this project are expected in autumn 2014. Moreover, the reassessment of all the invertebrates assessed to date will give us valuable insights about the change in conservation status of Europe's invertebrates and monitor progress towards halting the loss of biodiversity by 2020.

Strengthening the link between science and policy

The European Red List contributes to enhancing the general understanding among policymakers and the general public of the importance of threatened species and the need for conservation action in Europe. It provides detailed and up-to-date information on aspects of biodiversity to help establish conservation priorities at the EU and pan-European levels in order to guide conservation action. Below, we examine some of the key conservation policies in Europe, and ask how the science-policy interface can be strengthened through monitoring natural capital.

The EU Nature Directives and the Bern Convention

EU nature conservation policy is based on two main pieces of legislation – the 1979 Birds Directive [34] and the 1992 Habitats Directive [35]. Both Directives contain a series of Annexes that identify the habitats and species of European Community concern.

The Annexes of the Birds and Habitats Directives have changed little since their establishment, with only few changes made related to the enlargement of the European Union. An adaptation of the Annexes of both Directives has been called for by various stakeholders on several occasions, in particular because of the very few invertebrate species listed in the Annexes of the Habitats Directive. Annex II and IV of the Habitats Directive [35] list 162 species of invertebrates (122 arthropods, 39 molluscs and one echinoderm). The European Commission will use the European Red List as the key source of information when undertaking the possible adaptation of the Annexes in the future.

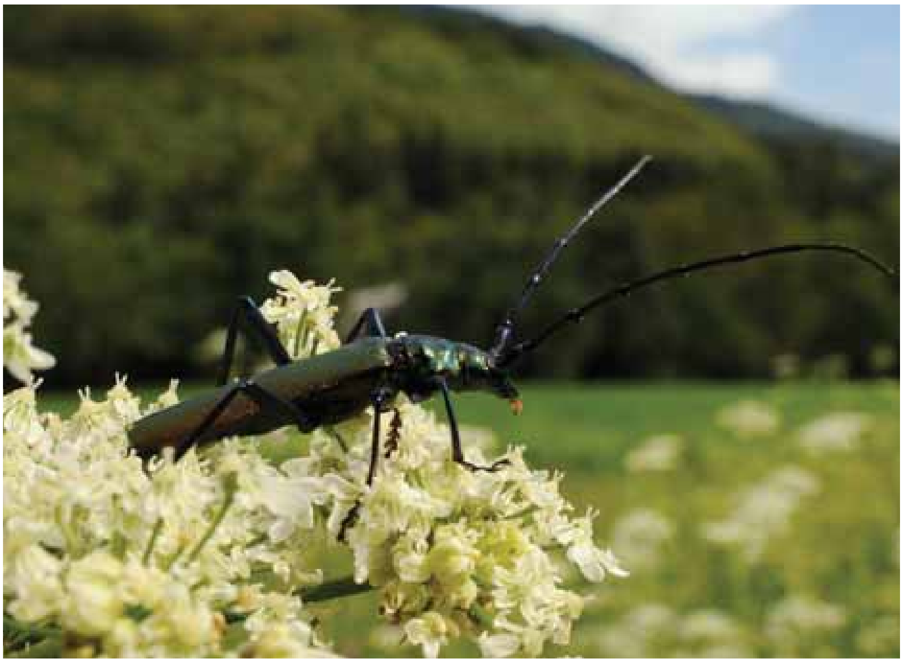
For countries outside the EU but within Europe, the Bern Convention is the main instrument that places a particular importance on the need to protect vulnerable species and lists these species in its Annexes. Annexes II and III of the Bern Convention [36] list 70 species of arthropod, 39 species of mollusc, four species of echinoderm, one species of annelid, five species of cnidaria and eight species of sponge. The European Red List will also provide the basis for a future review of these Annexes. These uses of the Red List highlights the role Red List data plays in advising policy and legislation.

Tracking progress towards meeting policy targets

At the European Union, the European Council committed to a new long-term (2050) vision and mid-term headline target for biodiversity in the EU for the period beyond 2010, which is '*To halt the loss of biodiversity and the degradation of ecosystem services in the EU by 2020 and restore them in so far as possible, while stepping up the EU contribution to averting global biodiversity loss*'. This headline target underpins the EU 2020 Biodiversity Strategy [37] that specifically calls for a time-bound, quantified target to accelerate the implementation of the EU Nature Directives and achievement of the objectives set out in them.

To respond to the need to know whether this target is being met, the EU developed the EU 2020 Biodiversity Baseline [38], which provides facts and figures on the state and trends of the different biodiversity ecosystem components, and data for measuring and monitoring progress in the EU from 2011 to 2020. The Baseline is based on what is considered to be the best available data, and considers the data resulting from the European Red List.

Musk beetle (*Aromia moschata*) © Nick Upton / RSPB images



Robber fly © Patrik Katona

Informing conservation action and guiding funding allocation

The information in the European Red List includes data on the distribution of the species, the habitat requirements, threats that need to be addressed and conservation actions that are recommended, so Red List data can be used to identify species that require specific conservation action, and to help develop conservation programmes and recovery plans. Besides providing information on how successful protection of a species of Community interest listed in EU legislation might be, it provides a broad overview of the status of species beyond those listed and protected in the Directives.

Through the EU's financial instrument for the environment, the LIFE+ programme, the EU supports environmental and nature conservation projects, funding projects that focus on improving the status of species of Community Interest. However since the development of the European Red List, the LIFE+ programme does also give priority funding to those projects that aim actions towards conserving threatened species according to the European Red List.

framework, taking into account national needs and priorities, while also bearing in mind national contributions to the achievement of the global targets [40]. National Red Lists of threatened species may provide suitable data for reporting on progress toward these goals and for informing national conservation priority setting [7,41].

By using quantitative information from a Red Listing assessment, two consecutive Red Lists on a given set of species can illustrate the change in extinction risk faced by that group, using the Red List Index [42]. Though developed at the global level, a National Red List Index or Regional Red List Index can be calculated based on the same process. Compiled at regular intervals, National Red Lists are valuable biodiversity indicators, reporting biodiversity trends at the national level and providing critical information for reporting to international conventions such as the CBD [7,43-44].

Unfortunately, countries vary in their capacity to monitor biodiversity [45] and those countries with the least capacity tend to be custodians of the greatest quantity of wildlife. Least is known about the status of species

We extend that analysis to look more closely at those countries that have included invertebrates on National Red Lists. There are 59 national Red Lists with invertebrate species assessments. Figure 06 shows that the majority contain species of arthropods, followed closely by species of molluscs. Terrestrial and freshwater invertebrates are more frequently assessed than their marine counterparts. The most popular group assessed are insects (Figure 06). The most popular groups assessed are butterflies, dragonflies and damselflies, beetles and orthoptera, a group that includes grasshoppers and crickets.

Invertebrate coverage on National Red Lists requires additional investment. Figure 07 shows that there are large gaps where no invertebrate species are included on National Red Lists, particularly in the African continent, and large areas of South East Asia.

Conclusions

Given the importance of invertebrates in defining what humans benefit from ecosystems, nations are not doing enough to measure changes in invertebrate species status. The European regional initiative

Figure 05 | Total funding provided per taxon to European species supported by the EU LIFE-Nature program.

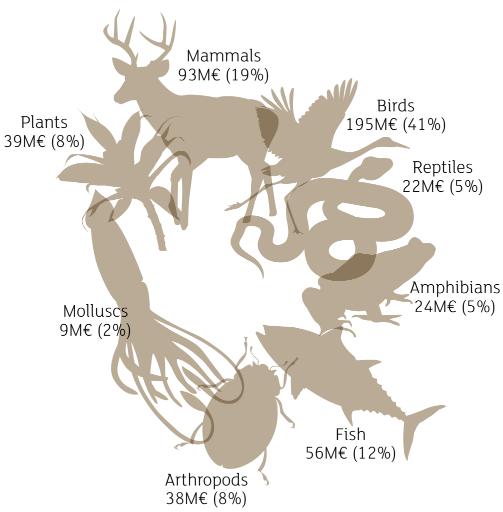
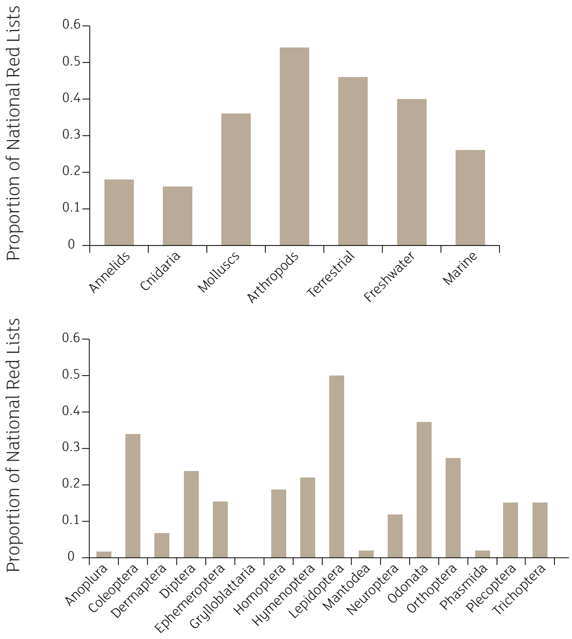


Figure 06 | For those national Red Lists that contain invertebrate species assessments (n=59) we show the proportion of those which have assessments for species in each of four main invertebrate phyla and the division between terrestrial, freshwater and marine invertebrates (top), and the proportion of those which have species in each insect order (bottom).



This approach offers an opportunity for more funding available for invertebrate species conservation.

Expanding national level approaches to measuring natural capital

Following creation of environmental targets such as the Aichi Targets under the Strategic Plan for Biodiversity [39], information on status and trends of biodiversity at the national level has become increasingly important to both science and policy. The need for national responsibility for reporting has come to the fore as nations are invited to set their own targets within this flexible CBD

where diversity is greatest. A recent study by Zamin *et al.* [7] evaluated the taxonomic and geographical gaps in national threatened species list coverage. Geographical gaps were most apparent in western and central Africa, Oceania and the Caribbean. Historically, invertebrates and plants have been poorly studied, but plants are relatively well documented in threatened species lists such as National Red Lists and certain invertebrate groups such as butterflies, dragonflies and molluscs are also well represented. Zamin *et al.* [7] showed that in a review of 109 countries, that 53% of countries with National Red Lists had assessed taxa within this species group.

presented above, and certain national level listings provide a model which other countries could follow to create their own measures of invertebrate natural capital. This would have the duel function of both providing an evidence base from which to measure future change in status, and a basis from which the biodiversity component of human benefits from ecosystems could be evaluated. Ultimately, natural capital must be properly accounted for by nations; national and regional Red Lists of invertebrates provide the baseline from which such decisions can be made.

Figure 07 | Maps showing locations of 59 countries that have invertebrate national Red List assessments, aggregated by invertebrate phyla (annelids, cnidarians, molluscs and arthropods) (left) and insect orders (right).

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Maybug (*Melolontha melolontha*) © Nick Upton / 2020 VISION / naturepl.com

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The expansion of agriculture and urban areas are the key threats to European invertebrates

Chapter 6
Hidden in plain view: effective invertebrate conservation for our future world

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Introduction
Why should we care if invertebrates go extinct? Probably 99% of all species that have ever existed on Earth have gone extinct through natural processes, especially major geological/atmospheric events, which have ranged from huge basalt outpourings at the end of the Permian to meteorite impact at the end of the Cretaceous. As the vast majority of all species on Earth today are invertebrates [1], and there may be roughly 10 million species on Earth today [2], this means that almost 1 billion species of invertebrates have succumbed to extinction. By comparison, the 10,000 or so species estimated to have gone extinct at the hands of human activity since the industrial revolution seem to pale into insignificance. Yet McKinney [3] estimates that at least a quarter of all insects are faced with extinction as a direct result of landscape transformation and habitat loss because of competition with humans for space and resources. Without a large scaling up of taxonomic efforts, in most of these cases, the species will disappear without us even knowing that they existed.

Against this backdrop of so much natural extinction, why should we care whether a few more species of invertebrates go extinct? First and foremost, as the main causal agent of modern extinctions and because of the intrinsic value of species [4], we are morally obliged to avert human mediated extinction. Secondly, species also have instrumental value, via the use of organisms for human benefit, and this often provides us with the best 'hard currency' for justifying conservation actions [5]. Chapters 1 and 5 demonstrate many of the benefits humans reap from invertebrates in both consumptive and non-consumptive use. The role they play in ecosystem functioning in particular may provide us with a wide range of benefits, which – if ecosystem function is compromised through the loss of species – could incur high economic costs to human society [6-8].

Getting to grips with invertebrate complexity
Given the fact that many species are not yet known to science and that we know surprisingly little at present about the roles of different species in ecosystem functioning, how do we best conserve valuable species diversity in our ecosystems? How can we conserve the instrumental value of invertebrates in particular, when in reality we do not know the magnitude of this value? What is understood is that different species such as worms, wasps and water fleas make different qualitative and quantitative functional contributions to ecosystem processes and food webs. However, levels of contribution not only differ between species: different developmental stages of a single species may represent different functional organisms (e.g. the caterpillar and the butterfly), which are involved in different ecosystem functions and hold different positions in the food web. This complexity of interactions becomes magnified, when one considers that 1,000 species in any one area at one time (a modest number of invertebrates by world standards) may be involved in potentially as many as half a million interactions with differing contributions to ecosystem functioning. Therefore, to conserve ecosystem function effectively, we must conserve interactions as much as the actual species, which often involves maintaining populations at current levels.

As the relationship between species and provision of ecosystem services is not well understood we must take the precautionary approach, to invertebrate conservation, which allows us to deal with the immense complexity

Praying mantis © Aniket Sardana

Acorn weevil (*Curculio glandium*) © Anthony Roberts / www.iamzed.co.uk

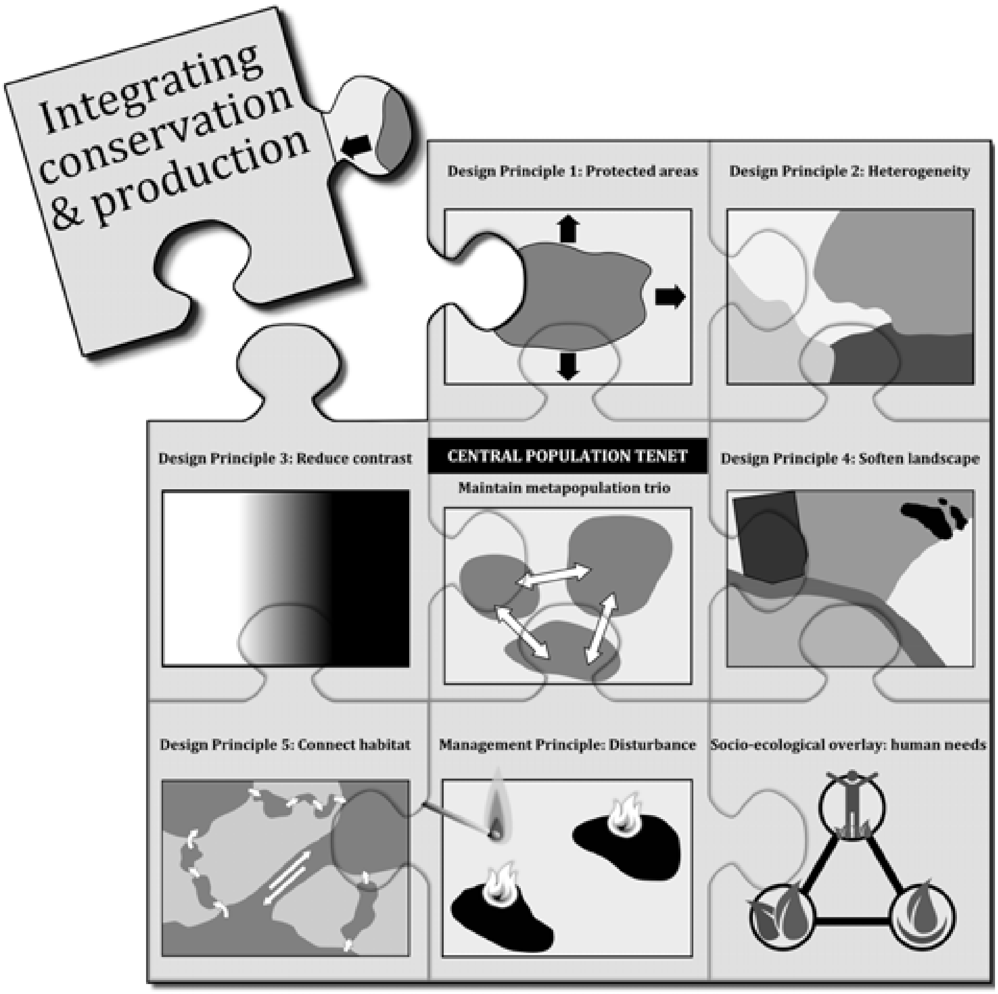


Figure 01 | The different operational perspectives, design principles and one management principle which underpin the landscape approach for terrestrial and freshwater species

of the invertebrate world as well as our lack of knowledge about it. For example, precaution should have us assume that each species contributes to some ecosystem process somewhere at some time [9], though the magnitude of their contributions will of course be different. This means that each and every species is important, as each one makes some contribution to the functioning of at least one particular community. Furthermore, novel threats to ecosystems emerge over time, such as climate change, which are often caused by a multitude of impacts (such as increasing frequency of weather events). A precautionary approach to conservation must therefore cater for extreme scenarios rather than average ones, and include future projections of threats and their effects, even though we rarely know about the timing of these threats or the form that they will take.

For example, because there may be a drought in an area in one year and then a flood in the next, we must carry out *contingency planning*, i.e., planning for survival through the worst possible conditions. This conservation distillation means putting into practice the *precautionary principle* [10], which tells us to use our best insight on the information that we have from across the globe to put into place a set of conservation guidelines that are going to prevent further extinctions of populations and species. Often this type of information is either lacking, or comes with great uncertainty, simply because fully understanding that complexity is beyond current scientific resources. This is especially so given the shortage of time to engage conservation action before there are too many more extinctions and ecological regime shifts where ecosystems are irrevocably changed in state.

Conceptual approaches to invertebrate conservation

One way forward for invertebrate conservation is to consider various approaches which maximize the opportunities for conservation, so that as many significant species and species interactions are conserved as possible. These approaches need to be universally applicable, anywhere where there are terrestrial, freshwater or marine invertebrates and other biodiversity, and include the three operational perspectives of landscapes or seascapes, features of the landscape or seascape, and species. In this section (Figure 01) we introduce the different operational perspectives, design principles and one management principle which underpin the landscape approach for terrestrial and freshwater species. In Box 01 (Figure 02), we also discuss additional important aspects which feed into the design of conservation strategies, such as the importance of maintaining metapopulation dynamics, and incorporating the needs of human communities. A key finding is that all these approaches and principles are interlinked and it is their instigation together that maximizes conservation of all natural components and interactions across the landscape.

Operational perspectives on invertebrate conservation

In order to effectively conserve invertebrate diversity, approaches are needed that are scientifically sound, are continuously evaluating their progress towards the set goal, and are tractable for practical conservation action. One promising model for invertebrate conservation is to take the spatially explicit approach of landscape-scale conservation, as this is one essential spatial scale at which most conservation efforts are focused.

Orb-weaver spider (*Nephila* sp.) © Trond Larsen

These types of approaches firstly recognize contingency planning and the precautionary principle, and may be viewed from four operational perspectives:

1) coarse filter (landscape),
2) mesofilter (features and patches in the landscape) [11],
3) fine filter (species conservation), and
4) the socio-ecological filter (the human communities, consideration of which is essential to realistic conservation action).

The coarse filter refers to conservation of naturally viable and resilient ecosystems. These have to be developed out of the landscape mosaic, which consists of both disturbed patches (such as agricultural fields, plantations, urban developments, and transportation corridors) as well as natural ones. The key point in a successful strategy is to promote indigenous structural, compositional and functional biodiversity while at the same time allowing optimization of human activities where the degradation cost of these is offset by the conservation action. In short, the human structuring and ordering of the landscape must maintain indigenous biodiversity and allow natural ecosystem function to continue, based on information of the natural condition and then monitoring to ensure that this state is maintained.

In turn, the mesofilter focuses on those features of the landscape that are critical for life functions of species. These may include patches of mud, outcrops of rock, a fallen log,a sunny bank, as well as nuances of topography such as hilltops and low lying areas that create flow of water and nutrients across the landscape and create wetland systems.

The fine filter or species conservation focuses on particular species, usually threatened ones, in all their life stages and developmental morphs (which are often highly significant for invertebrates). Often however, the conservation of a species implies an awareness of the importance of conserving a range of interactions between the focal species and other species in association with it. An obvious example is that of a pollinator and its flower where there cannot be conservation of one without the other. However, all these subtleties of interactions between species are not generally known, so a valuable first step is to define the true habitat of a species, which is the area containing all the conditions necessary for a species to carry out all its life functions (and includes features of the mesofilter operational perspective) [12]. The viable habitat of a butterfly for example may have to include a preferred plant for oviposition, conditions suitable for a mutualist ant, a hilltop for meeting a mate, flowers for nectar and sunny patches for basking.

The fourth operational perspective is an overlay of a socio-ecological filter. This filter integrates the social needs of the local human communities into the conceptual model. Consideration of this filter is essential in our modern world, as there will be no sensible and effective conservation unless the needs and aspirations of local people, and of trade, are considered. Most commonly, this will involve focusing on an intact landscape and its features (i.e. intact coarse- and mesofilters) so as to benefit the local populace, rather than directly focusing on the specific merits of a single invertebrate species. However, sometimes local people may want to focus specifically on a particular flagship species (i.e. engage the fine filter overlay) as is the case of a Zulu community focusing on the Red Listed Karkloof Blue butterfly [13]. Using the socio-ecological overlay or filter, the needs of humans are also considered across the integrated landscape matrix.

All the filters discussed above are enmeshed with each other. They are not mutually exclusive, and can be considered as interactive overlays, with the mesofilter and

Ladybird © Trond Larsen

Box 01 | Design and management principles for invertebrate conservation

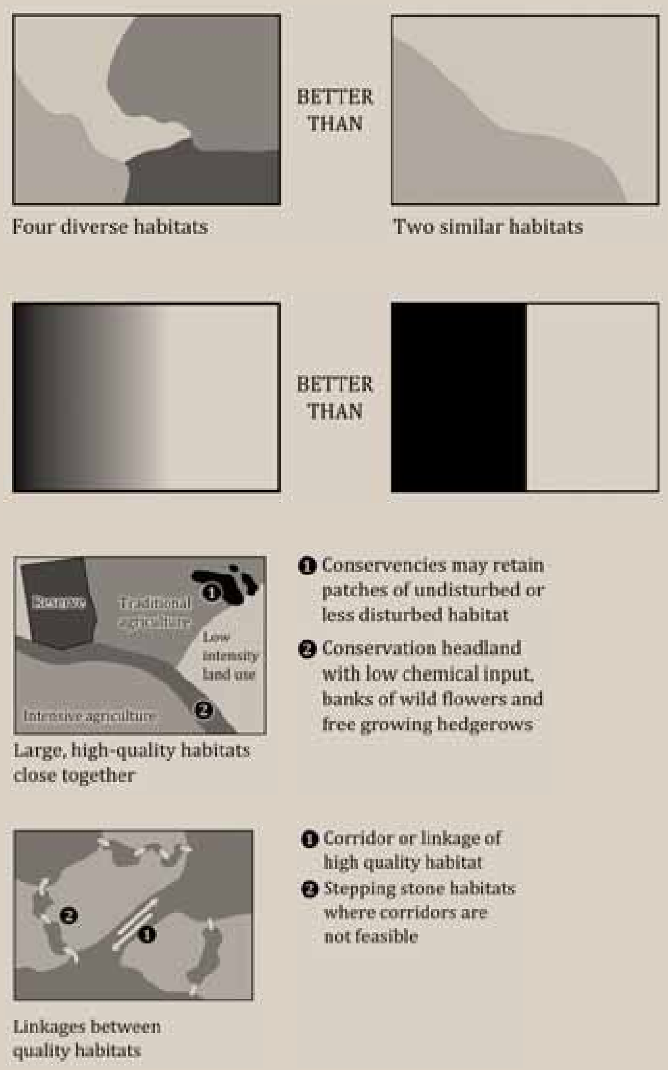
Any landscape conservation activity has two fundamental facets: design and management. Design principles are essentially related to landscape structure, and inevitably must consider other landscape descriptors, such as contrast (extent of difference) and context (types of difference) between different patches or landscape elements in the mosaic [14]. These are important as they forge new combinations of landscape structure, and hence give more opportunities for invertebrates, with the interfaces or ecotones having distinct biodiversity attributes [15]. The five, interrelated design principles are [16]: 1) *maintain protected areas*, 2) *maintain as much quality landscape heterogeneity as possible*, 3) *reduce contrast between landscape elements*, 4) *outside reserves, soften the landscape,* and 5) link areas of quality habitat across the landscape (Figure 02). These linkages or corridors, as well the nodes to which they are connected (protected areas or patches of quality habitat), can be developed into large-scale ecological networks, which emergent properties beyond simple corridors [17].

The second facet of landscape-scale conservation activity, management, is basically what we do with the design i.e. how we manage it. This can be extremely important, with one insect study showing that it can be 2-5 times more important than design itself [18].

Most landscapes experience some disturbance, whether abiotic, such as fire or flooding, or biotic, such as grazing impact from large herbivores. These disturbances may be patchy and at small spatial scales (e.g. trampling around waterholes) or extensive (e.g. run-away grassland fires). The aim of the management principle is to simulate these natural conditions, with particular attention to extent, intensity and timing of the management activities.

Employing all the above principles for maintaining population levels of species in a naturally dynamic landscape ensures gene flow among populations. Large patch sizes can sustain larger population size, good patch quality makes conditions suitable for maximum population viability, and reduced patch isolation via improved connectivity between patches allows movement between and recolonisation of habitat patches. This interactive trio of large patch size, high patch quality and reduced patch isolation may be considered as a central population tenet which maximizes opportunities for metapopulation dynamics, and so increases the survival opportunities for species.

Figure 02 | The maintenance of habitat heterogeneity, reducing contrast between disturbed and natural areas, softening the landscape outside protected areas, linking patches of quality habitat, and simulating natural disturbance.



the fine filter superimposed on the coarse filter, and the socio-ecological filter influencing the landscape mosaic. In turn, the value of features and patches on the landscape for quality biodiversity conservation depends on the presence of an intact or healthy landscape, and likewise, so do particular species of conservation concern.

The importance of monitoring

One last consideration is that the effectiveness of interventions must be measured and monitored for continual improvement to practical conservation design and management. Invertebrates can play a valuable role in indicating wider impacts of conservation in this continual re-assessment process. For example, in the context of South African forestry, grasshoppers and dragonflies are being used to measure quality of terrestrial and freshwater ecosystems, respectively [19-20]. Sometimes this re-assessment process leads to some new perspectives on landscape design and management and should be appreciated as a continual learning process. For example, certain corridors such as power line servitudes which were previously considered 'waste land' turned out to be valuable for pioneer species, and grazing by cattle can simulate grazing by indigenous megaherbivores.

Invertebrate versus vertebrate conservation

Vertebrate conservation is usually species-specific, although of course many protected areas conserve a range of species [21]. Although in some instances, invertebrate conservation action adopts a species-specific approach [e.g. 22], as we have seen above practical conservation of most species and their interactions has a spatially explicit dimension (e.g. there is action across the landscape) upon which we may or may not superimpose specific species considerations, such as threatened species management. Because of the deeply ingrained species-specific approach of the vertebrate conservation movement, it has often been deemed difficult to engage policy makers or the general public in the concept of landscape-level conservation approaches employed by invertebrate conservationists. Many authors have discussed this at large; specifically, Cardoso *et al.* [23] have summarised current shortcomings within their discussion of the seven impediments to invertebrate conservation, which we will use as a framework for comparing and contrasting the invertebrate and vertebrate conservation movements. However, we must bear in mind that specifically the first two 'impediments' are in many ways a failure of the conservation community rather than obstacles *per se*.

Grass-skipper © George J. Reclos

1. Invertebrates and their ecological services are mostly unknown to the general public (the public dilemma)
While no doubt the same holds true for many vertebrate species, this does not matter to the same extent as for invertebrates, because vertebrates such as birds and mammals are generally conserved for their individual charisma and perhaps because our closer relations with vertebrates (and in particular mammals) trigger a higher level of empathy. Having said that, it is unlikely that many members of the public know about the importance of pollination by bats or seed burial by mice. Perhaps the problem here is that in invertebrate conservation there is too much focus on the nuts and bolts (the perceived need to know the functional roles of all invertebrate species in order to justify conservation action), when the overriding message should be about respecting all life and keeping the ecosystem intact *as a whole*. In fact, given the gaps of knowledge about invertebrates, their interactions and the importance to ecosystem functioning, it is vital that we put out a conservation message which buffers against this lack of knowledge by applying the precautionary principle.

Vertebrate conservation relies to a large degree on charisma of species and clear communication of the underlying conservation issues, while invertebrates receive much less 'marketing' to the public. Perhaps the common misconception here is that the general public does not care about invertebrates to the same level as it does for vertebrates. However, it is unlikely that a child's first wildlife encounter is with a cheetah, a deer or even a mouse, but most likely with an earthworm, butterfly, or grasshopper. Phobias, such as arachnophobia (which of course has a biological base) aside, most of us are fascinated with 'creepy crawlies', especially as children. This means that it is important that as conservationists we build on this innate fascination with invertebrates. As with vertebrate conservation, the way to improve perception about invertebrates is to expose the grace, beauty and sheer diversity of invertebrates through the camera, especially now that technology has advanced enough to do so (e.g. the British Broadcasting Corporation's production *Life in the Undergrowth* reached millions of viewers). The key, as many vertebrate conservationists know, is to illustrate the functional value of invertebrates through intriguing stories and fascinating pictures and sounds.

Every story needs a hero, and so by using communication technology and media wisely, we can create invertebrate icons. It is vital that we identify 'insect cheetahs' or 'worm rhinos' as the poster species of invertebrate conservation. After all, this is what vertebrate conservationists do with supreme confidence. In this regard, the camera and public engagement are the invertebrate conservationists' most useful tools.

2. Policymakers and stakeholders are mostly unaware of invertebrate conservation problems (the political dilemma)
It has often been deemed difficult to engage policy makers and stakeholders in invertebrate conservation problems. While this is often seen as a consequence of not being noticed or being drowned out by vertebrate conservationists, there are in fact many policymakers and stakeholders who understand the importance of invertebrates. The International Union for the Conservation of Nature (IUCN), for example, has an established Invertebrate Conservation Sub-Committee and full representation on the Steering Committee of the IUCN Species Survival Commission. Organizations such as The Xerces Society in the USA and Buglife in the United Kingdom are regularly consulted on many issues affecting invertebrate conservation. National and regional Red Lists are more and more incorporating invertebrates into assessments and the emerging notion of natural capital will no doubt advance the importance of invertebrates on the political agendas (see Chapter 5). Nevertheless, in those cases where policymakers and stakeholders are still deaf to concerns about invertebrate conservation, invertebrate conservationists can and still have more to do. Again, clear and confident communication is key, and needs to take advantage of mainstream conservation and species icons. After all, this is the way that vertebrate conservationists do business.

3. Basic science on invertebrates is scarce and underfunded (the scientific dilemma)
Basic invertebrate science funding is scarce; greatly so relative to the numbers of species for which it is required. We therefore need to urgently search for general principles, especially at the landscape level, whereby as many species as possible as well as their interactions are conserved. These must include 'typical' landscapes that were formerly much more widespread, as well as unusual or unique ones. This means having some sort of effective triage in place, based on the precautionary principle. In other words, we need effective ways forward which efficiently consider landscapes as conservation and management units, while also taking into account the various species responses within those landscapes [24]. In addition, particular iconic species can be chosen to attract funding, while less charismatic species can be made into icons through Red Listing. For example, the Pygmy hog sucking louse *Haematopinus oliveri* from India would probably be known to only a handful of people had it not been Red Listed as Critically Endangered [25]. Species icons can also be used to sketch principles for species conservation across the various landscapes, with careful consideration given to the fact that even closely related species, which may have different conservation statuses, may have subtle but critical differences in traits [26] (see also number 7 below).

Similarly, undertaking conservation assessments of groups of invertebrates can make good use of limited funding resources. Sampled Red List assessments for example are useful for deriving an overall picture of the conservation status of invertebrates and help in prioritising efforts at a broad-scale [27-28]. Lastly, we should always remember that a lack of funding is as much an opportunity for developing new approaches to solve problems

A quarter of all insects could face extinction over the coming century

Moth (*Zygaena carniolica*) © Marco Bertolini

Weaver ant (*Oecophylla smaragdina*) © P. Jeganathan

as it is a hindrance. A key here is to take a leaf out of the book of vertebrate conservationists, where individual iconic and threatened species are given a high profile and where resulting landscape conservation approaches (such as protected area advancement) aim to cover the needs of these icons as well as smaller and less charismatic species alike.

4. Most species are undescribed

Cardoso *et al*. [23] and Samways *et al*. [29] have emphasized the importance of having named species as the base unit for fine filter, as well as many coarse filter, conservation projects. Species have traditionally been the common currency of conservation, while the success of projects has often been measured against variables such as the number of species saved [30] or by using key species as indicators of success etc. [31]. Even when using the landscape approach, we still need to know how well we are doing in terms of setting aside or re-naturalizing landscapes. Particular indicator species enable us to assess the success of these set aside or restoration activities.

Furthermore, a central concept to conservation prioritisation is that of conservation of endemic species. Such prioritization requires sound taxonomy and species recognition in the field. While effective surrogates and bioindicators are critical in these activities, their selection must be carried out with great care, and tested for efficacy [32]. While there are many potential surrogates for biodiversity, few have been rigorously tested; the fact that a favourite taxonomic group is promoted to be a good surrogate should not necessarily be relied upon [33]. Many terrestrial, freshwater and marine invertebrates, rather than vertebrates or even plants, are particularly good as bioindicators, as they are sensitive, abundant, often have small home ranges, and are easily sampled in fairly large numbers. What all this means is that conservation into the future requires good taxonomy and good, user-friendly field guides. It is therefore essential for *all* conservationists to keep lobbying for the funding for more alpha taxonomy and the transfer of taxonomic and species identification skills between researchers, conservationists and citizen scientists alike.

5. The distribution of described species is mostly unknown

As Cardoso *et al*. [23] point out, without reasonable information on where species live, it is impossible to know which species are threatened and where to concentrate efforts to conserve them. Nevertheless, much has recently been achieved using large-scale regional or global assessments of selected invertebrate taxa [e.g. 27]. For example, broad scale patterns of threat and its distribution at a global or regional scale are now available for a number of invertebrate groups, such as freshwater crayfish, crabs [34] and molluscs [35], dragonflies [36], dung beetles [37], butterflies [38], and saproxylic beetles [39] (see chapters 2-5). However, in order to effectively track trends in extinction risk over time, Red List re-assessments require new and revised sets of distributional data, nominally every ten years. This is a tough challenge even for those invertebrates already listed, let alone any new ones. This is largely because of the lack of funding for research expeditions and targeted surveys in previously under-researched parts of the globe. Because of the volume of species involved, and the survey methods required, this represents a much greater challenge than that faced by vertebrate conservationists [40]. It also increases steeply as more invertebrate species are added to the Red List.

6. The abundance of species and their changes in space and time are unknown

The scale of this challenge is similar to that set out under point 5 above. While the population dynamics of a greater proportion of vertebrates are understood than those of invertebrates, vertebrates perform less well as bioindicators of subtle changes in landscape condition, owing to their generally greater mobility [41]. However, the spatial and temporal dynamics of invertebrate taxa of conservation concern is barely known. It is only in a few localities around the world, especially in the temperate north and parts of temperate south, that the population dynamics of a few species are known, notably of butterflies [42]. Well-studied taxa can be used to determine the status of other lesser-known taxa, as well as the ecosystem as a whole, via the collection of abundance as well as presence/absence data.

Flesh fly (*Sarcophaga* sp.) © Nick Upton / naturepl.com

Coleopteran species on flower © Roberto Pedraza Ruiz

Ladybirds © Brad Bushey Photography

Selection of focal taxa and standardization of protocols have a long way to go and fall far behind the data gathering used by large vertebrate monitoring programmes, where game and bird counts are carried out regularly in particular reference or priority areas. Yet a start has been made, for example, with regard to ants [43], carabids [44] and butterflies [45-46]. Despite these encouraging signs, there is still not enough synthesis of invertebrate surveying, which is partly a reflection of uncertain and insufficient funding. Progress is likely to be made through the involvement of citizen scientists, which offers a cost-effective way of carrying out much needed surveys. In terms of citizen science projects, however, charismatic mammals and birds are still scoring better than invertebrates, though there are some notable exceptions (e.g. UK Natural History Museum Bug Count - http://www.opalexplorenature.org/). Nevertheless, there are regular butterfly counts in some European countries which have contributed an enormous amount of data [47]. Improved use of electronic media is likely to increase our ability to collect, share and explore data in novel ways, as has been done for vertebrates (e.g. InstantWild application - www.edgeofexistence.org/instantwild/), and this will no doubt benefit invertebrates [48].

7. Species' ways of life and sensitivities to habitat change are largely unknown

With so many invertebrates still awaiting description, it is not surprising that even less is known in terms of the life history and ecology of many invertebrates. This is particularly so as invertebrates are principally ectothermic and so many are known to have particular habitat preferences, and are often in restricted or confined geographical areas. This includes special habitats in caves, epiphytes, bracket fungi, acid bogs and probably thousands more. Furthermore, larval stages often require different conditions from that of the adult. Where research has been done, we have often been surprised by the extreme sensitivities of some species. For example, the tropical beetle *Africobatus harpaloides* can only tolerate a change in temperature of 0.9˚C [49]. The extremely localized and phylogenetically curious troglobitic crustacean *Spelaeogryphus lepidops* only lives along a few metres of one subterranean stream running through a sandstone cave in southern Africa. Nevertheless, studies of invertebrates tracking climate change in the recent geological past [e.g. 50] have shown that many species can be remarkably resilient yet do not necessarily follow the same dynamic biogeographical patterns as their associated plants. In short, this is truly a massive and important challenge which requires much more attention if we want to ensure the health of our habitats and ecosystems in the face of an uncertain future. The key issue with the shortfalls highlighted in points 5-7 lies in the limited and highly competitive funds which are available for biodiversity research and species surveys. In many cases, invertebrate biologists compete with vertebrate, plant and fungi biologists for limited resources. Yet opportunities exist for synergies between different fields of biology to address data gaps in a novel and timely manner, and by pooling and sharing expertise across the globe we can step by step further our understanding about the sheer diversity of invertebrates.

Pebble prominent (*Notodonta ziczac*) © Anthony Roberts / www.iamzed.co.uk

Invertebrate conservation success

Despite the complexities of invertebrate conservation and the challenges that it faces, conservation success stories are not just confined to vertebrates. The following provides a selection of notable advances and successes, and highlights the principles and approaches detailed above, as well as the way in which perceived 'impediments' can be overcome to benefit invertebrates and biodiversity as a whole.

Freshwater invertebrate recovery after removal of invasive alien trees, South Africa

Invasive alien organisms are one of the greatest threats facing indigenous biodiversity. In South Africa, invasive alien trees along river courses have had a major adverse effect upon the biota and hydrology. In response, there has been a major national initiative, the Working for Water Programme, which has targeted river courses in particular to remove invasive alien trees to improve hydrology (soften the landscape), supply jobs for local people (add to the socio-economic filter or overlay), and to restore biodiversity.

It soon became apparent that removal of trees led to an immediate recovery of stream invertebrate species, with three species of dragonfly only known from locations where alien trees had been removed. Their original habitat had been obliterated by the alien trees, principally through their canopies shading out low vegetation for their life functions (mesofilter habitat), and also creating dark conditions unsuitable for the adult. Nevertheless, there must have been sites where various species still occurred, but these were so limited that despite intensive searches none were ever found [51] (Photo 01).

What has happened is that certain threatened dragonfly species have now been given what is in effect reprieve from extinction, with remarkably fast recovery, even by narrow range palaeo-endemics. There could even have been Centinelan extinctions (extinctions before scientific discovery and description), as two new species to science were discovered only where alien trees had been removed. The same results were found for many aquatic macroinvertebrates, although the difference was that certain narrow range endemics did actually benefit from the shady conditions of the alien trees, and declined temporarily when the alien trees were removed before time had elapsed for the indigenous trees to grow [52].

Photo 01 | With removal of alien pine trees across the landscape (a coarse filter perspective), there was a remarkably rapid recovery of indigenous plants and freshwater fauna, including several Red Listed species, such as the Mahogany presba dragonfly (*Syncordulia venator*) (a fine filter perspective) (inset). Main picture & Inset © Mike Samways

Photo 02 | Cousine Island, Seychelles, was fully restored to its historic condition through removal of alien vertebrates and many alien plants, restricting the area of agricultural production, and re-planting the coastal plain (a coarse filter perspective). This restoration was possible as much natural capital still remained among the granite boulders (a mesofilter perspective) on what had become a highly degraded island. This restoration enabled many invertebrate species to recover, in particular, the Red Listed yet keystone Seychelles giant millipede (a fine filter perspective) (inset). Main picture & Inset © Mike Samways

Restoration and management of Cousine Island, Seychelles

Like many tropical islands, the Seychelles archipelago has suffered some major environmental degradation. However, several projects are on-going to restore some of these islands, including Cousine Island. Restoration on the island began in the 1970s, at which time environmental degradation had reached severe proportions, from overgrazing, impacts from domestic cats and several species of invasive alien plants, and extensive cultivation.

Over the last 40 years, intensive restoration has returned the island to its historical condition (a coarse filter perspective). This has been possible through recognition of some key issues. Owing to its rocky, granitic nature, and despite the landscape degradation, there were still enormous amounts of natural capital remaining in and among the granite boulders (i.e. showing the significance of the mesofilter). In other words, many species still occurred in low numbers by retreating among the rocks. Nevertheless, there were some island extinctions recorded, but only for vertebrates. Declines of significant invertebrate species such as the Seychelles giant millipede (*Sechelleptus seychellarum*), a soil-making and threatened species, did occur (a fine filter perspective). With the natural capital intact, albeit at low levels, and with targeted management, such as the eradication of all alien vertebrates, removal of all major stands of invasive alien plants, and the re-afforestation with natural plant communities, the island was returned to its historical condition [29] (Photo 02).

However, there was a last twist that threatened to undo the whole of the restoration process. The invasive alien ant *Pheidole megacephala*, which had been on the island for many years, entered into a new phase of population explosion as it went into mutualistic association with alien honeydew-producing heteropterans, a scale (*Pulvinaria urbicola*), a mealybug (*Dysmicoccus* sp.) and a cottony scale (*Icerya seychellarum*). Together these insects were threatening the keystone and threatened tree *Pisonia grandis* as well as other species. This can be viewed in terms

Stick grasshopper © Michael Tweddle / Tweddlefoto.com

As the main causal agent of modern extinctions, humans are morally obliged to avert species extinction

of the power of the fine filter threatening a coarse filter activity. An immediate and rapid response was required, with ant toxic baiting being the best option. However, there was great risk as many rare and threatened endemic species of both vertebrate and invertebrate could be at risk from any baiting strategy. In the end, a targeted approach was taken where a highly specific bait was discharged into specially designed bait stations to which only the ant had access. This bait station approach worked, and the populations of the ant and alien heteropterans collapsed, with recovery of endemic herbivores [53] (Photo 03).

Weta recovery, New Zealand

At times, some invertebrate species have been deemed charismatic enough to warrant species-specific conservation actions to be taken (i.e. to apply the fine filter of species conservation). One particularly good example is that of weta recovery. Weta are large-bodied flightless Orthoptera which are endemic to New Zealand. Overall, there are over 70 species of weta in the country, with some species, such as the giant weta (*Deincranida* sp.) reaching 70 mm in length. Many *Deincranida* species have declined in the past, due to predation by introduced mammals, especially rats and mice, habitat destruction by humans, and habitat modification from non-native browsers.

As with vertebrate species threatened by the effects of introduced predators, simply providing a well-designed landscape allowing for invertebrate conservation and socio-economic growth is not enough. Species recovery can only take place in these instances if the threat is removed, i.e. if the introduced predator is eradicated, predator-proof fencing establishes a habitat island or the species of conservation concern is translocated to offshore, predator-free islands. In the case of the Cook Strait giant weta, *Deincranida rugosa*, translocation to offshore islands has secured a future for the species.

The Cook Strait giant weta was formerly common on the New Zealand mainland, but went extinct on the mainland from the effects of invasive predators and habitat loss. It persisted only on offshore islands, and conservation intervention successfully increased its range by translocations to additional islands, such as Maud Island in 1976 and Matiu/Somes Island in 1996 [54]. The species has now made a return to the New Zealand mainland, where it has been introduced to the Zealandia (formerly known as Karori) Sanctuary, a predator-proof reserve on the outskirts of Wellington.

The Department of Conservation is following a precise plan of action for the preservation of wetas in New Zealand [54]. This comprises the management of selected (or, in the case of some species, all) populations and their habitat in order to maximise the opportunities available for weta, as well as the establishment of new populations through translocations. For example, in the case of the Cook Strait giant weta, translocations were supplemented with mice eradication on Mana Island (the species' stronghold and source population for previous translocations), which has helped to increase the species' abundance. Such management intervention is particularly successful with invertebrates because they generally have high intrinsic rates of productivity and will often recover quickly given the chance. Similarly, captive breeding programmes have been established for some of New Zealand's threatened weta species, such as the Middle Island tusked weta (*Motuweta isolata*), in order to aid releases to establish new populations in addition to that on Middle Island [55].

Above all, raising public awareness has been central to the weta recovery strategy, as has a reporting mechanism accessible to all

Photo 03 | As restoration of Cousine Island was nearing completion (a coarse filter perspective), there was a severe outbreak of the big-headed ant *Pheidole megacephala* which, in association with honeydew-producing insects, was causing dieback of certain trees, including the keystone tree *Pisonia*. On the left are ants attending high levels the cottony cushion scale. On the right is a *Rodolia* ladybird which immediately appeared once the ant had been precision controlled with bait, and immediately began to suppress the scale host (a highly targeted fine filter approach to improve the landscape for certain rare and threatened species of tree and invertebrate). Both pictures © Mike Samways

Nursery web spider (*Pisaura mirabilis*) © Nick Upton

which has even led to the discovery of new weta populations [54]. The success of weta advocacy shows that achieving iconic status among invertebrates is far from impossible. For example, liaising with the local community in King Country and garnering the support of local landowners has helped to establish the Mahoenui giant weta reserve and to ensure the ongoing survival of the Mahoenui giant weta.

Butterfly conservation: monitoring schemes and citizen science

While invertebrates in the past have often been overlooked in conservation planning, the beauty and diversity of butterflies has long captured the imagination of the general public. As a result, butterflies have enjoyed conservation attention disproportionately to many other insects or invertebrates. Butterfly conservation efforts therefore provide us with excellent case studies on how to overcome some of the 'impediments' often associated with invertebrate conservation, namely by setting up long-term monitoring schemes and engaging with citizen scientists.

The first Butterfly Monitoring Scheme started in the UK in the mid 1970s [56] and has since prompted the development of similar schemes elsewhere in Europe [57] and across the globe (e.g. the annual Fourth of July Butterfly Count organized by the Xerces Society in the USA and the North American Butterfly Associations annual counts in the USA and Canada). The methods of many of these monitoring schemes is based on counts of butterflies along fixed transects, and are often carried out biannually. Many of these transect counts are carried out by skilled volunteers, and these schemes thus provide a valuable insight into what is possible when volunteer manpower is harnessed for species monitoring.

Within Europe, the presence of at least ten established monitoring schemes (e.g. UK, Ireland, France, Netherlands, Belgium, Germany, Switzerland, Slovenia, Estonia and Finland; [47]) has led to the European Environmental Agency (EEA) recommending the development of European butterfly indicators which rely on the data from these monitoring schemes. For example, a preliminary European Grassland Butterfly Indicator has shown an alarming 50% decline in grassland butterfly populations between

34,000 people took part in the UK's Big Butterfly count in 2011

Peacock katydid (*Pterochroza ocellata*) © Trond Larsen

Photo 04 | Large-scale ecological networks are interconnected linkages of remnant vegetation (here, indigenous grassland, bushes and a stream) among disturbance patches (here, pine plantation blocks) so as to maintain biodiversity and to allow ecosystem function as a finger-like extension of a protected area (seen here on the horizon in the middle background) (a coarse filter perspective). In doing so, certain species (the fine filter) are also protected, like the imperilled katydid *Paracilacris periclitatus*, a Red Listed species (inset). Main picture © Mike Samways, Inset © Piotr Nascrecki

1990 and 2005 [47].

In addition to using skilled volunteers carrying out standardized monitoring, many citizen science projects have sprung up in recent years. For example, Butterfly Conservation (a UK-based charity) has been organizing an annual butterfly count for a number of years whereby the general public submits sightings of butterflies from parks, gardens and public spaces. In 2011, over 34,000 people took part with more than 320,000 butterfly and moths sightings recorded (www.bigbutterflycount.org). This allows comparison of relative abundance of species between years and adds greatly to the available distribution information for certain species. Similar citizen science-based projects are now becoming established for other taxa and habitats. For example, another UK-based charity, Pond Conservation, has initiated nation-wide monitoring of garden pond biodiversity to keep track of freshwater invertebrate (and other taxa) status. Naturally, schemes like this rely on effective communication and the distribution of easy to use guidelines and identification material in order to reach as wide an audience as possible. Specifically, making results publicly available using a variety of media is crucial to enhance the sense of inclusiveness and contribution amongst participants.

Instigation of large-scale ecological networks, South Africa

Globally there is a move to more sustainable forestry practices, with Forest Stewardship Council (FSC) certification ensuring best practices. Among the approaches being developed is the implementation of large-scale ecological networks (ENs) of remnant vegetation and other biota in between the plantation patches. This coarse-filter approach is a major undertaking in South Africa, with about a third (500,000 ha) of the land set aside for this purpose. The main challenge has been to design and manage the landscape to maximize biodiversity conservation and ecosystem processes while also allowing production to take place on the remaining two-thirds, following the design and management principles set out above.

The results to date have been very encouraging, with large-scale ENs having emergent principles over single corridors, and in doing so, making them important habitats *per se*, and not just simple movement corridors. This is achieved by ensuring first of all that the corridors or linkages making up the ENs (as well as extensive nodes) are wide enough to overcome edge effects from the pines, their effect of which extends 30 m into the remnant grassland. This means that corridors need to be over 60 m wide if they are to be more than just edge habitat. Nevertheless, narrow edge-zone corridors still have value as movement corridors (for example for butterflies, which fly 13 times faster in narrow compared to wide corridors in the EN) and for early successional species, as in the case of some grasshoppers (a fine filter perspective). However, the most valuable EN corridors are the wide ones (>200 m) which contain many of the natural features (mesofilter) inherent with the natural landscape. These include topographic features both high (hills) and low (wetlands), as well as rocky outcrops, seeps, dry patches etc., and especially natural habitat heterogeneity [58]

What these ENs have done for indigenous biodiversity is positive, with many taxa benefitting from their implementation (Photo 04). In short, the reality is that there is production on the landscape yet also biodiversity conservation to the extent that the set aside land (i.e. the ENs) act like protected areas in terms of structure, composition and function [59]. In addition, the local human communities are included in the process (see Figure 01) and so the socio-ecological filter is included alongside the coarse filter, mesofilter and fine filter, in both the design and management of these ENs. Furthermore, after these plantations receive FSC certification, the timber is then exportable to Europe. And so there is a win-win situation with both biodiversity conservation and timber production at their most efficient, all across the same landscape.

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Cover photo:
The praying mantis (Mantodea) is found across southern Europe is one of the most well known species of Mantids. Like all species in the group, *Mantis religiosa* are formidable predators, able to turn their heads 180 degrees. With two large compound eyes and three other simple eyes located between them, their deceptive camouflage aids them in ambushing and stalking prey.

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