



Measuring the changing state of nature

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Most attempts to quantify the impact of humanity on nature and bring it to public attention have centred around estimates of extinction rates. Suggestions that these figures have been exaggerated are, in our view, misplaced, but extinction rate estimates do face other problems – inevitable uncertainty, an arguably weak link to economic value, and insensitivity to short-term change. We therefore look here at other large-scale measures of the changing state of nature, focusing on recent analyses of trends in population size, numbers of populations and habitat extent. In spite of being limited by sampling inadequacies, these data provide a sensitive short-term complement to the long-term perspective gained from considering extinction rates that can be linked directly both to economic values and to public concerns. Although further work is needed on extinction rates, we conclude that significant new emphasis should be placed on instituting broader, more systematic monitoring of habitats and populations.

For almost a quarter of a century, much of the effort put into quantifying the scale and significance of the impacts of humans on our fellow creatures has centred around assessing rates of species extinction [1–12]. This is understandable: ongoing attempts to clone ancient DNA from mammoths [13] and thylacines [14] notwithstanding, extinctions are forever. Estimating rates of human-driven extinction thus addresses a major moral concern. Nevertheless, quantifying extinction is difficult, and extinction rates are relatively insensitive to short-term changes in human impacts. Against this background, it is timely to look at measures of habitat loss, and at newly emerging meta-analyses of changes in populations. These too suffer from undersampling and biases in coverage, but are more sensitive to short-term changes in drivers, and are linked more immediately to economic concerns about the value of ecosystem services.

Concerns about extinction rates

Because species greatly outnumber field biologists (and most of these study species-poor groups [15,16]), we have reasonably comprehensive information about recent extinction rates for only a handful of more readily studied, species-poor groups (such as birds, large mammals and

palms [7]). We have little data with which to infer how representative extinction rates for these taxa are for biodiversity as a whole. Moreover, educated guesswork suggests that biologists have described less than half and perhaps <10% of all the species on Earth [4,17]. Hence, any extrapolation from extinction rates for well-known groups to estimates of the total number of extinctions per year across all groups is impossible. Instead, conservation scientists usually estimate extinction rates in relative terms as the proportion of species going extinct during a given interval, or as average species life spans [2,6,12].

A related difficulty is that, because of the scarcity of fieldworkers, most extinctions (even in well studied groups) go unwitnessed. Therefore, extinction rates are usually estimated using indirect techniques, such as combining data about habitat loss with models of how species numbers change with habitat area [2,3,5–11], or extrapolating from the rate of progression of threatened species through Red List categories ([18], but see [19,20]). These methods again build from empirical studies of only a handful of groups.

The reliance of biologists on indirect estimates lies at the centre of another, high profile criticism of extinction rate estimates [21]. Lomborg rejects estimates based on habitat loss by arguing that they have rarely been tested, and that predicted rates are contradicted by the documented persistence of forest bird species many years after widespread deforestation in the eastern USA, Puerto Rico and the Atlantic forest in Brazil. The solution to this apparent paradox is that extinction is often a protracted affair [22–24]. Following partial habitat clearance, for instance, the relaxation of a community to its reduced habitat area can take a century or more [11,25,26], during which time the persistence of tiny populations of doomed species can give the misleading impression that species losses are not as severe as predicted. This is why conservation scientists are usually careful, when estimating current impacts, to talk in terms of the rate at which these commit species to eventual extinction, rather than about instantaneous rates of loss. Detailed tests that take this subtlety into account – by tallying not just extinctions but also numbers of species independently assessed as being on the edge of extinction as result of habitat loss – provide fairly strong support for habitat-based extinction rate estimates, in each of the areas that Lomborg flags, as well as elsewhere [9,23,27–31].

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A more serious set of difficulties emerges from the need to place contemporary losses in a geological context [32,33]. This requires comparison with pre-human rates, derived from the fossil record. But the fossil record is incomplete for all groups and poor for several of those, such as birds, for which we have reasonable estimates of recent extinctions. For all taxa, the fossil record is also unavoidably biased towards widely distributed, abundant species, which have disproportionately low extinction rates. These and other uncertainties surrounding background rates compound those associated with contemporary estimates. A novel attempt to combine both sources of uncertainty using fuzzy numbers reported that best estimates of mammal extinction rates over the past 400 years are between 36 and 78 times background levels, somewhat less than the figure of 87 times background derived if uncertainties are ignored [33]. However, given that most peer-reviewed studies estimate impending losses at between 10^3 and 10^4 times background [7–9,18,34], considerations of uncertainty seem unlikely to alter the broad picture. Although there is still disagreement over whether human-caused losses will in due course parallel the Big Five mass extinction events [35–37], there is little doubt among recent commentators that what is unfolding is indeed exceptional [11,12,22–24,33,35–39].

Thus, in spite of concerns about extrapolation from a few well known groups, about having to use indirect techniques, and about problems in comparing current and past trends (all of which affect other measures of the state of nature), extinction rate estimates do provide an important measure of human impacts over the long term. That said, there are two other reasons why focusing solely on extinction rates as the main metric of human impacts on nature would be unwise. First, although the moral case for preventing individual extinctions can be compelling, the economic case can be portrayed as weak [21]. This is because in assessments of the overall economic value of natural systems, the larger and more robust numbers tend to come from direct uses of wild populations, and especially from the provision of ecosystem services [40–42]. Yet almost inevitably, the last few individuals of a threatened species will be incapable of sustaining any substantial harvest, and will probably not make a major, measurable contribution to ecosystem function – ecological extinction typically precedes the complete disappearance of a species. Option, existence and bequest values are likely to be higher for threatened than for common species, but these are generally lower, less tangible, and less easily estimated than are the value of goods and services.

Second, the difficulties in documenting extinctions and the time lag between habitat loss and species disappearance mean that measured extinction rates have considerable inertia. Rather like the course of a supertanker, the current course of extinction rates reflects actions undertaken in the past, whereas present-day activities might not yield demonstrable changes for several years. By contrast, if conservationists are to better understand and mitigate the impact of humans on natural systems and policy makers are to be accountable for their decisions over the course of electoral cycles, we need to supplement the long-term perspective afforded by extinction rates with

measures of the state of nature which are sensitive to short-term changes in anthropogenic pressures.

Trends in populations and habitats

With these issues of insensitivity and the need for immediacy and tangible economic value in mind, what other global measures of the changing state of nature are available? Broadly speaking, these fall into two types: measures of habitats, and measures of populations.

Dealing first with habitats, most attention has focused on forest cover. According to the latest FAO assessment [43], the period 1990–2000 saw net changes of around -0.8% per year for moist and dry tropical forest and $+0.1\%$ per year for temperate forest. These estimates have attracted criticism because the techniques used to generate them differ between countries, because they conflate into a single net figure losses of primary forest and gains in secondary forest and plantation and, above all, because changes in methods and definitions mean that they cannot be easily compared with FAO assessments for earlier intervals [44,45].

A more systematic analysis has recently been reported by Achard and colleagues [46]. Focusing just on tropical humid forests, they examined losses between 1990 and 1997 using fine resolution satellite data for a carefully stratified sample of 100 sites disproportionately concentrated in areas of rapid clearance. From these, they estimated annual net clearance at 0.43% with an additional 0.20% being ‘visibly degraded’ each year. These figures for net forest loss turn out to be some 23% lower than the FAO estimate for the same countries ([43,46]; see also [47]).

Deforestation rates also underpinned an early attempt to look at global rates of loss of populations. By combining preliminary estimates of the probable total number of populations of all species with FAO forest loss figures for the 1980s, Hughes and co-workers suggested that tropical forests could be losing 0.8% of their populations – perhaps 16 million individuals in total – every year [48]. More recently, work by the same group has switched to estimating population losses from historical contractions in the ranges of reasonably well mapped mammal species [49]. Their work indicates that 173 species of declining mammals have lost an average of 68% of their historical (effectively nineteenth-century) range, measured in terms of $2^\circ \times 2^\circ$ grid cells. It would be worthwhile to extend this analysis to all mammal species, including those not known in advance to be declining. However, resulting estimates of decline will be conservative because the relatively coarse resolution needed to map even quite well known species throughout their ranges underestimates real losses (as substantial range contraction can occur without a species becoming completely absent from a $2^\circ \times 2^\circ$ cell [49]).

A complementary approach has been to look at changes in population size rather than range. Many populations of vertebrates, plants and even invertebrates have been monitored over quite lengthy periods, for differing reasons. Combining the resulting data on within-population trends across species has yielded some striking insights into overall changes in the state of nature. For example, annual breeding bird census data collected by the British Trust for

Ornithology and the Royal Society for the Protection of Birds have enabled them to monitor population trends for most of the commoner breeding species in Britain since 1962. When the trends within species were aggregated across habitat types, they provided clear, broad-based evidence (to put alongside a handful of autecological studies) that farmland and, to a lesser extent, woodland birds in Britain have been in decline for several years [50–52] (Fig. 1a).

A similar cross-species compilation has been attempted for amphibian populations worldwide [53]. Combining trends data for 936 populations of 157 species, Houlahan and colleagues concluded that populations declined markedly from the late 1950s to the late 1960s, since when the decline has continued, albeit at a reduced rate (Fig. 1b). The temporal and spatial patterning of these losses has since been questioned by re-analysis using an analysis of variance approach to take account of differences between years in the set of populations being recorded [54], but the overall finding – that there has been a marked decline in amphibian numbers worldwide – remains robust [55].

More ambitious still, WWF International and the UNEP-World Conservation Monitoring Centre have initiated the Living Planet Index (LPI), an annual synthesis of trends across 694 populations of mammals, birds, reptiles, amphibian and fish [56–58]. The index is compiled separately for forest, freshwater and marine populations. Species coverage is driven by the availability of studies, and similar to the Houlahan *et al.* amphibian synthesis, the LPI is affected and perhaps biased both by selection of unrepresentative populations and by discontinuities in the data. However, the overall pattern is again clear: the three indices combined have declined by ~37% over the past 30 years, with declines being most severe in freshwater (54% decline between 1970 and 2000), followed by marine and forest populations (35% and 15%, respectively [58]; Fig. 1c).

Most recently, we have been involved in an attempt to collate and synthesize all up-to-date estimates of global trends in population size or habitat extent [59,60] (Fig. 1d). In spite of uncovering many excellent regional and local

assessments in both the published and grey literature, we could find global estimates of habitat change (spanning at least five years since the 1992 United Nations Conference on Environment and Development) for only four out of 14 major biomes (tropical forest [43,46]; temperate and boreal forest [43]; seagrass [61]; and mangroves [62]). Our coverage was somewhat improved by adding-in LPI estimates of average changes in vertebrate populations of freshwater and marine systems and temperate and tropical forests [58], together with FAO data on changes in the proportion of marine fish stocks that are at an exploitable level [63]. For tropical forests, we found that vertebrate populations are apparently declining faster than habitat extent (as might be expected given current levels of exploitation for food [64,65]), but in general, where more than one data type was available, there was rough agreement between datasets in the overall status of a biome [60]. Across all assessed biomes, the mean rate of change since 1992 has averaged between –0.7% and –1.1% per year (depending on whether one takes a simple or an area-weighted mean of the averages for each biome), although these figures should be treated with caution because of the complete lack of data for many major biomes.

Limitations to population and habitat data

This brief survey of recent large-scale analyses of the status of habitats and the populations they contain reveals several significant and recurrent problems. As with extinction rates, there are taxonomic, geographical and habitat biases in what we know about: most populations and very many habitats are not monitored at all. For example, the LPI contains no data at all about invertebrates or plants (although some are available), and relatively few data series from the tropics [58]. Likewise, in our search, we could find no global estimates of changes in the extent of relatively intact grasslands, rangelands, deserts, tundra, coral reefs, algal beds, swamps, lakes, rivers or estuaries [59,60]. We are evidently monitoring only a small fraction of living systems.

Second, understanding the significance of those data that are collected is hampered by undersampling [49], by

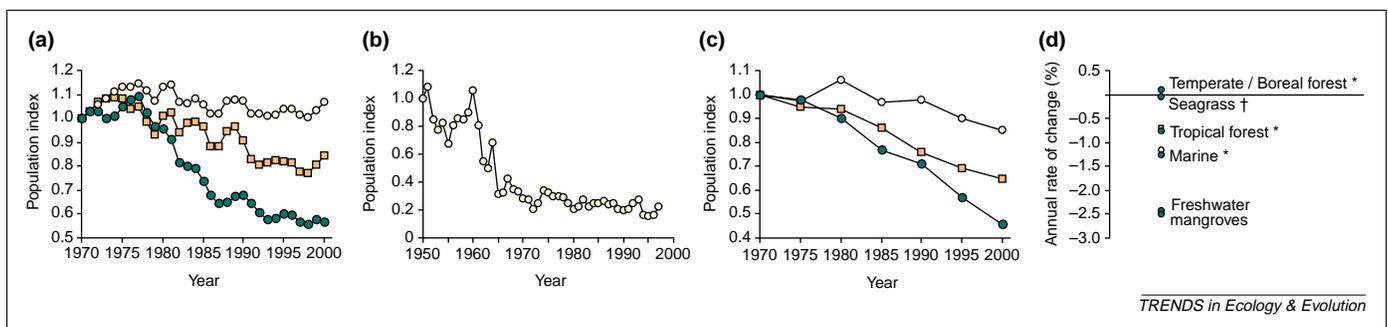


Fig. 1. The results of recent synthetic analyses of trends in the status of populations and habitats. (a) Mean population sizes of the commoner breeding bird species in Britain, 1970–2000; species counts are standardized to 1.0 for 1970, and then averaged across all species in a category (data from [50]); yellow circles, all species ($n = 105$); orange squares, woodland species ($n = 33$); green circles, farmland species ($n = 19$). (b) An index of amphibian populations worldwide, 1950–1997, based upon accumulated annual changes in a sample of 936 populations; the index is arbitrarily set to 1.0 in 1950 (data from [53]). (c) An index of vertebrate populations for forest (yellow circles), freshwater (green circles) and marine (orange squares) biomes, 1970–2000; the index is derived in a similar fashion to (b), and is based on 282, 195 and 217 populations, respectively; counts are standardized to 1.0 for 1970 and then averaged across all species in a category (data from [58]). (d) Mean annual rates of change in area or vertebrate abundance of six biomes, using data spanning at least five years after 1992; the simple and area-weighted [40] grand means across all biomes are plotted as a yellow circle and an orange square, respectively; *, mean of more than one estimate; †, little confidence can be attached to this value [61] (data from [59,60], with updating).

variation in techniques [43], by problems of definitions [43,46,48], and by the statistical difficulties of combining datasets with variable temporal coverage [53,58]. Each of these problems can potentially be solved in future assessments, although other difficulties, such as the problem of combining trends across different taxa or habitat types, are likely to remain.

Third, there are clearly some types of data that we are barely collecting at all. In particular, although we have some quantitative information on broad changes in the size of populations or the extent of habitats, we lack data about more detailed attributes that could have a disproportionate effect on ecosystem health. This is especially important for habitats such as grasslands, coral reefs and the open ocean, where degradation is a greater problem than wholesale conversion. In these and other habitats, we simply do not know enough about the effects of anthropogenic modifications (which might not show up as gross changes in habitat area) on valued attributes such as the persistence of species and ecological and evolutionary processes, and the continued delivery of key ecosystem services [41,59].

Strengths of population and habitat data

These concerns notwithstanding, even the population and habitat information that we do have has several strengths. In spite of the small sample sizes and resulting noise, most trend estimates seem to be accurate to within a factor of two either way – considerably less than the order-of-magnitude uncertainty surrounding extinction rate estimates. Different measures of rates of change also appear to be roughly consistent within biomes [60], and taken globally, they suggest that we are losing somewhere between 0.5 and 1.5% of wild nature each year. Given the extremely rapid and accelerating increase in the scale of the human enterprise since the mid-20th century, these annual losses are also in rough agreement with aggregate estimates that we have now in total cleared somewhere around 50% of natural habitats [66]. In brief, the numbers are already quite robust.

These figures are also sensitive to short-term changes in human pressures. Differences among European countries in population trends of farmland birds correlate well with recent agricultural policies and practice [67], whilst slowdowns in the Brazilian economy show up as reductions in rates of forest loss across the Amazon [68]. The time lag between our actions and a detectable signal of their impact on nature can be very short, and for some systems might shorten further as remotely sensed data increase in coverage, sophistication and availability.

Losing populations (many of which provide us with harvested goods) and habitats (which provide essential services) also has immediacy in terms of its material significance. The overexploitation which led to the collapse of the Grand Banks groundfish industry in the early 1990s led to the losses of tens of thousands of jobs and has already cost the Canadian Government ~US\$2 billion in welfare and re-training programmes [69]. Moreover, such population collapses are in practice rarely reversible over the short to medium term [70]. We recently calculated that, taken globally, the average annual loss of wild habitats

and populations deprives humanity of goods and services with a net worth, after deducting the value of converted systems, of perhaps US\$250 billion for that year and every year into the future [59].

Last, and of crucial importance, rapid losses of often familiar populations and habitats might have far greater resonance with the public than would the less rapid (although biologically, even more worrying) extinctions of often less familiar species [52]. Annual losses of 0.5% to 1.5% add up to losses of 15% to 35% over a single generation: people notice changes of that magnitude. Public concern in turn means that population and habitat changes are becoming targets for political action, with trends in Britain's breeding birds, for example, now one of the UK Government's 15 headline indicators of sustainable development [50], and with similar initiatives now underway Europe-wide (R. Gregory, pers. commun.).

What next?

We believe that monitoring populations and habitats is an extremely valuable and relevant way of assessing human impacts on nature, and one that, in several ways, provides an essential complement to measures based on extinction rates. The challenge now is to significantly expand the scale, scope and consistency of existing habitat and population monitoring schemes, ideally in concert with a rolling extension of the current Millennium Ecosystem Assessment programme [71] (<http://www.millenniumassessment.org/>).

In particular, we see a need for the taxonomic, habitat and geographical coverage of monitoring to be considerably enhanced, so that all regions and biomes and a larger and more representative sample of major taxa are assessed. This in turn will require the properly planned development of sampling regimes that are carefully stratified across space, time and taxa. In addition, there is an urgent need to develop new systems for monitoring detailed, quantitative changes in the dynamics of habitats and populations, to get a clearer picture of degradation (as opposed to outright loss), of changes in habitat and population viability, and of changes in the delivery and value of vital ecosystem services (for some ideas, see [72]). This scaling up of monitoring will not be cheap, but there are ways in which it can be made more affordable – through the expanded use of volunteers, for example [52], and through the further development of remote-sensing techniques, underpinned by ground-truthing. Finally we believe it is essential that these monitoring programmes, whilst being made as cost-effective as possible, have secure long-term funding: without this, we will only ever see blurred and fragmented snapshots, rather than the whole picture.

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