Supplementary Online Material for Balmford (ms#1073947) for the 8/9 issue.

Case Studies

All values were converted to 2000 US$ using a GDP deflator index (*S1*). Where case studies gave ranges of values, we took midpoints. All figures were taken directly from the sources cited, except for the coral reef example, where the time schedule for yields from destructive fishing was estimated from figure 2 of (*S2*) as 36 tonnes km^{-2} in year 1, and then 3 tonnes km^{-2}, rising to 5 tonnes km^{-2} by year 10.

Rates of Loss

We searched the published literature and available databases for global estimates of recent trends in the area of largely unmodified habitats in all the relevant biome categories of Costanza *et al.* (*S3*) except rock and ice and open ocean. We supplemented this with biome-specific indices based on time series data on populations of wild vertebrates, derived from the WWF 2000 Living Planet Index (LPI) and FAO fisheries data (*S4*, *S5*). Unless otherwise stated, annual percentage rates of change in area or index value were calculated by taking the values a_1, a_2 in the first year t_1 and the last year t_2 of the series under consideration and calculating $100*(1 - (a_2/a_1)^{(1/(t2 - t1))})$.

Tropical forests: We used the estimate in the FAO Forest Resources Assessment 2000 (*S6*) of a global net change of –7% in the area of tropical forest for the period 1990-2000, yielding an annual decline of 0.8%, although we are aware that some authorities consider this an underestimate. The LPI Index (*S4*) for tropical forest vertebrates showed a decrease of 26% between 1970 and 1999, yielding an average annual decline of 1.1%.

Temperate and boreal forests: The FAO Forest Resources Assessment estimates that temperate and boreal forests have increased in extent by 1% during the period 1990-2000, yielding an annual increase of 0.1% (*S6*). The LPI Index (*S4*) for temperate forest vertebrates showed a change of +4% between 1970 and 1999, yielding a small annual increase of 0.1%.

Mangroves: Valiela *et al.* (*S7*) estimated on the basis of a comprehensive assessment of mangrove resources that at least 35% of the global area of mangrove forests has been lost in the past two decades. Their data yield an annual decline of at least 2.5%.

Swamps, floodplains, lakes and rivers: There are no global estimates for rates of change in the extent of these habitats or for overall changes in their condition. The WWF LPI (*S4*) for inland water vertebrates showed a decline of 51% between 1970 and 1999, yielding an average annual decline of 2.4%.

Grasslands, rangelands, deserts and tundra: There are no global estimates for rates of change in the extent of these habitats or for overall changes in their condition. The available data for vertebrate populations are currently inadequate to allow development of a reliable LPI for any of these biomes.

Coral reefs: Although Bryant *et al.* (*S8*) report that around one-quarter of the world's reefs are believed to be at high risk of degradation, there are no reliable global estimates for the rate at which coral reefs are actually being lost or degraded.

Seagrass and algal beds: There are no global estimates for the extent of algal beds, nor for rates of change in extent. No comprehensive survey of seagrass beds has been carried out, although it has been estimated that there may be between 500,000 and 1,000,000 km^2 in total (M. Spalding, personal communication). Short and Wyllie-Echeverria (*S9*) stated that perhaps 900 km^2 of seagrass beds had been lost globally between 1985 and 1995, although the basis for this is not clear. Extrapolation would give an annual decline of 0.01 to 0.02% although little confidence can be attached to this figure.

Estuaries: We found no global assessment of rates of loss or degradation of estuarine habitats.

Coastal shelf: The only measure of coastal shelf habitat modification for which we found global estimates was disturbance of the sea-floor by bottom trawling. However, it is not clear what proportion of bottom trawling caused long-term habitat degradation, so we have not used this estimate.

Marine: The marine component of the WWF LPI (*S4*) does not distinguish between different marine biomes. Overall it indicates a 36% decline in abundance of marine fish, mammals, birds and reptiles over the period 1970-1999, yielding an average annual decline of 1.5%. Further evidence for decline is provided by fitting a curve to FAO data (*S5*) on changes since 1974 in the proportion of all the world's marine fish stocks that are exploitable (i.e., with status categories other than unexploitable). Most fish stocks reduced to unexploitable levels show little evidence of recovery within 15 years of their decline (*S10*) and so can be regarded as effectively lost to exploitation for the foreseeable future. The fitted curve suggests that exploitable fish stocks have effectively been "lost" at the rate of 1.5% per year.

Thus for each of three biomes we have two estimates derived by different methods and either independent data (tropical forest and temperate/boreal forest) or largely independent data (marine LPI and fish stocks). In all cases the two estimates were remarkably similar. The rates of change were therefore averaged for these biomes to yield a single estimate. Five of the six global biome-specific estimates of change in habitat area or population show declines, which are distributed about a mean of 1.2% per year (SE = 0.5%; n = 6).

Costs of Losses

If the Costanza *et al.* aggregate figures (*S3*) for largely natural biomes and our estimate of the proportion of TEV lost upon conversion are roughly correct, then a single year's average losses in the 1990s cost society approximately \$37.6 trillion $\times$ 54.9% $\times$ 1.2% $\approx$ \$250 billion every year into the future.

Costs of Conservation

The hypothetical terrestrial reserve network would cover ~15% of each region (*S11*, *S12*). The costs include resources needed for the effective management of existing and new reserves; the costs of adequately compensating local residents in developing countries for the unmet private opportunity costs of existing, strictly protected reserves (spread over 10 years); the costs of surveying and then leasing or acquiring new reserves (spread over 30 years); and the private opportunity costs of greening forestry or farming in buffer zones around the margin of reserves, covering an additional 1.5% of each region's total area.

The cost of the hypothetical marine network was derived from a survey of current and unmet expenditure for 71 Marine Protected Areas (MPAs; A. Balmford, P. Gravestock and C. Roberts, unpublished data). Total management costs of MPAs can be predicted from their size (regression gives $\log_{10}$[annual cost, in 2000 US$] = 5.00 + 0.20 [$\log_{10}$(area, in km^2)], with $r^2 = 0.79$). The management costs of the hypothetical global network were then estimated by combining this relationship with the log-normal size distribution for 991 existing reserves (*S13*), which together cover 0.50% of the seas, and assuming 30% coverage is achieved by simple replication of this current network (note that this will overestimate total costs because plausible spatial patterns of network expansion inevitably lead to reserve merging and hence economies of scale). One-off set-up costs of MPAs were estimated at 7.3 times annual management costs (from $n = 4$ reserves, including [*S2*]), and were spread evenly over a 30-year implementation period.

Total costs for both the terrestrial and marine reserve system varied through the implementation period, from $32 billion to $54 billion per year, with a mean of $45 billion.

Benefits of Conservation

If Costanza *et al.*'s (*S3*) per hectare values of ecosystem services and our 54.9% estimate for the relative loss of TEV upon conversion are approximately correct, the proposed reserve network would safeguard annual flows worth $23.8 trillion × 54.9% × 30% ≈ $3900 billion at sea and (because a network covering 15% of land area would cover ~16.9% of the largely natural biomes [*S3*]) $13.8 trillion × 54.9% × 16.9% ≈ $1300 billion on land, or ~$5200 billion in total. However, under strict protection, those flows accruing from resource extraction would not be available. Remaining services constitute ~91.4% of all services by value, according to table 2 of (*S3*) (conservatively assuming all recreation is incompatible with strict protection). Hence a strict reserve network would safeguard annual flows with a net worth of ($23.8 trillion × 91.4% × 30%) – ($23.8 trillion × 45.1% × 30%) ≈ $3300 billion at sea, and ($13.8 trillion × 91.4% × 16.9%) – ($13.8 trillion × 45.1% × 16.9%) ≈ $1100 billion on land, or ~$4400 billion in total.

Sensitivity Analyses

Our qualitative conclusions remained robust to varying discount rates in the case studies between 3% and 10%, and to excluding tourism and live fishing benefits in the reef example. The ~100:1 ratio was also robust when (because they were not addressed in the case studies) we excluded all benefits and costs from open oceans, and decreased only as low as ~40:1 even when we made the unlikely assumption that nutrient cycling (the largest service not examined in the case studies) differed from all measured services in being delivered equally by intact and converted biomes.

References

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