CO$TING NATURE VERSION 1 MODULES
MODEL DOCUMENTATION ESPANOL

This section describes the science, equations and assumptions behind the modules and submodules used.

Costing Nature is aimed at incorporating ecosystem service provision and benefits information into the conservation prioritisation and planning. It focuses on water, carbon and tourism related services and on defining the magnitude and geographic pattern of these as potential services and as those realised (used) by local and global beneficiaries. Costing Nature starts by mapping individual services for water, carbon and tourism and then combines them with analysis of current pressure, future threats, biodiversity and conservation priority to produce an assessment of priority areas for conservation and careful management on the basis of all of these factors. This is done first using baseline datasets representative of the current situation. Users may then apply scenarios for climate, land use or land management change (such as for example removal of funding for a conservation area) and examine the impacts - in terms of change in ecosystem services - and implications for beneficiaries. In version 1 all outputs are expressed in relative terms as indices from 0-1 globally This is to represent priority across the the world and so that very different services and priorities can be combined in aggregate indices to which the user can then apply specific weights.

The model produces a series of summary maps which combine the outputs of many of the modules described below. These maps include:

Relative conservation priority index - conservation priority of the major conservation NGOs (see module: conservation priority)

Relative biodiversity priority index - combines relative richness and relative endemism for redlist (threatened) species for the groups mammals, amphibians and reptiles.

Relative aggregate nature conservation priority index (potential services) - this combines total potential services (for all services) and total nature conservation priority (which combines the relative conservation priority index with current pressure and future threat). Relative aggregate nature conservation priority index (potential services) is thus a measure of potential value for services coupled with conservation priority according to perceived value and risk of loss.

Relative aggregate nature conservation priority index (realised services) - this combines total realised services (for all services) and total nature conservation priority (which combines the relative conservation priority index with current pressure and future threat). Relative aggregate nature conservation priority index (realised services) is thus a measure of actual value of services coupled with conservation priority according to perceived value and risk of loss.

The Co$ting Nature model consists of a number of modules as described below.

MODULE : Conservation priority

Conservation priority is considered an index of priority for conservation based on the overlap of institutional conservation priorities for major conservation NGOs. This index combines the conservation priorities of BirdLife International (Endemic Bird Areas and Important Bird Areas), WWF (Global200 priority ecoregions), Conservation International (biodiversity hotspots and KBAs), Wildlife Conservation Society (Last of the Wild). Each of these is weighted equally and the conservation priority index is essentially the number of assessments overlapping: the more overlap of individual priorities, the greater the overall conservation priority.

MODULE : Water Quantity

Water quantity is each pixel is calculated as the water balance (rainfall minus actual evapotranspiration) cumulated downstream. See Mulligan et al. (2011) for a description of the global water balance dataset.

MODULE : Water Quality

Water quality is calculated as the human footprint on water index (Mulligan, 2009) in which the potential water quality in a pixel respresents the cumulation of upstream influences of point (mining, oil and gas, roads, urban areas) and non-point (pastures and croplands outside of protected areas) source potential sources of contamination. Each of these is given an equal weighting in terms of its capacity to generate contamination and for each pixel the human footprint index represents the percentage of water coming from upstream that is influenced by these point and non point sources. This is calculated as rainfall falling on these 'polluting' land areas as a percentage of total rainfall falling. Areas with extensive agriculture or urban areas will leave a significant footprint on water downstream. This may be diluted as waters coming from undisturbed areas or protected areas. The influence of small (areal) footprint sources such as mines or oil and gas will tend to diminish quickly downstream whereas large areal footprint areas will influence downstream waters for much further.

MODULE : Water Provisioning Services

Potential water provisioning services for each cell are first calculated as the sum of clean (i.e. no human footprint) water available from upstream. Realised water services are this available clean water where there are dams and in relation to population. The greater the downstream population, number of dams and actual water available, the greater the service provided. If there is plenty of water but no people or dams then there is no reliased service. In this way not all water provides a direct service, only that water that is accessed and used. Where there is high available water and either a dam or high local populations the water services index will be higher. Untapped water services are considered to be the difference between potential and realised water services. All these indices are scaled from 0-1 between the minimum and the maximum for each map. The beneficiaries of realised water services are local dams, populations, irrigation projects etc.

MODULE : Carbon Services

Both carbon stocks and carbon sequestration make up the carbon services index. Potential and realised carbon services are equal since it is assumed that all carbon storage and sequestration contributes a service to global beneficiaries. Carbon stocks are calculated from the carbon stocks map of Ruesch and Gibbs (2008). Carbon sequestration is calculated from a global analysis of Mulligan (2009) based on SPOT VGHT imagery every 10 days from 1998-2008. Relative stock (t/km^2) and relative sequestration (t/ha/yr) are calculated and combined in a single relative index of carbon service.

Ruesch Aaron and Holly K. Gibbs. 2008. New IPCC Tier-1 Global Biomass Carbon Map For the Year 2000. Available online from the Carbon Dioxide Information Analysis Center [http://cdiac.ornl.gov] Oak Ridge National Laboratory Oak Ridge Tennessee.

Mulligan, M. (2009) Global mean dry matter productivity based on SPOT-VGT (1998-2008). http://geodata.policysupport.org/home/global-mean-dry-matter-productivity

MODULE : Biodiversity

Biodiversity is not a service *per se* but is important culturally, aesthetically and as a potential supporting framework for ecosystems and the services that they provide. Biodiversity loss is therefore to be avoided whereever possible. Two elements of biodiversity are considered as important for conservation prioriity: (a) species richness (number) of threatened species and (b) endemism or range size rarity of threatened species. The data available makes these calculation possible for mammals, amphibians and reptiles. The Costing Nature biodiversity index thus combined relative species richness of threatened mammals, amphibians and reptiles and relative range size rarity using the C-value (Barthlott et al., 2001). Species richness and endemism are equally weighted in the combined index.

Barthlott, W., V. Schmit-Neuerburg, J. Nieder, and S. Engwald (2001). Diversity and abundance of vascular epiphytes: a comparison of secondary vegetation and primary montane rain forest in the Venezuelan Andes. Plant Ecology 152: 145–156.

MODULE : Recreation

Potential recreational services are calculated according to the potential natural attraction of an area (defined according to its conservation priority index), with its accessibility to populations. Areas that are high conservation priority and accessible to significant populations and urban centres receive higher potential recreational services values (for both local and international tourism) than low conservation priority areas or areas that are less easily accessible. Urban areas are masked out of the analysis since the focus here is on nature tourism not on urban tourism. Potential recreational value is calculated as cumulated population weighted accessibility from each urban centre outwards. Accessibility is defined using the agglomeration index of Uchida and Nelson (2009). This is calculated only for non-urban and sub-urban areas and is multiplied by the conservation priority index. Where accessibility or population or conservation priority is high this will increase the potential recreation index. As always the index is expressed 0-1.

Realised recreational services will only be a fraction of the potential services because many potentially godd recreational sites will not be realised because of infrastructural, market, development and political or security barriers to tourism. We produce an index of realised recreational services using the online georeferenced photographic database of Panoramio which contains more than 5 million georeferenced photographs. Photographs uploaded to this database are considered to represent evidence of high value urban-rural or international tourism having taken place. The Panoramio database has been 'scraped' for the number of georeferenced photos by different users (i.e. the number of tourists having taken photos) per 25km. These are interpolated to the standard simterra grids at 1km or 1 hectare resolution and masked to remove photographs in urban areas. Finally a conversion to relative index (0-1) indicates the areas with lowest and highest realised tourism services.

Uchida, H. and Nelson, A. (2009) Agglomeration Index: Towards a New Measure of Urban Concentration. Background paper for the World Bank's World Development Report.

MODULE : Threats and pressures

In addition to value for ecosystem services and biodiversity, one has to consider risk of loss in any conservation prioritisation. Risk of loss/damage can be assessed from measures of current human pressure on the system and of future threat. The index of current pressure is given as the combination of relative population, relative fire frequency, relative grazing intensity, relative agricultural intensity, relative dam density and relative infrastructural density. Relative population is calculated on the basis of population density. Relative fire frequency is based on an analysis of the mean burn frequency from 2001-2010 from the MODIS burnt area product (Mulligan, 2010). Grazing intensity id calculated according to head of cattle for managed grazing and wildland grazing after Wint and Robinson (2007). Agricultural intensity combines the fractions of cropland and pasture in each pixel. Pressure from dams is calculated as the cumulative upstream number of dams using the Global Dams Database (Mulligan et al, 2009). Infrastructural pressure is calculated from the location of dams, mines, oil and gas, roads and urban infrastructure. Relative pressure is again scaled from 0-1. Threats are distinct from pressures because pressure refers to current pressure whereas threat is the potential to increase pressure into the future. The costing nature relative threat index combines threats of land use change, climate change and infrastructural change. All threats are assumed to be related to accessibility to populations through the roads network. The threat of deforestation is assumed to scale with proximity to existing deforestation fronts according to MODIS VCFchange, threats from infrastructure are assumed to scale with projected change in GDP and threats from population to scale with projected population change. Threats from climate change are assumed to scale with 17GCM ensemble projected IPCC AR4 A2a temperature and precipitation change to the 2050s. Finally remote threats such as mining and oil and gas (that may be distant from populations, urban areas and roads) are assumed to be greater in proximity to existing nighttime lights. All of these threats are given equal weight and scaled from 0-1 in the final threats map.

Mulligan, M. (2010) Fire-burn frequency dataset based on MODIS burnt area product. http://geodata.policysupport.org/fire-burn-frequency
Mulligan, M. Saenz-Cruz , L., van Soesbergen, A., Smith,V.T. and Zurita,L (2009) Global dams database and geowiki. Version 1. http://geodata.policysupport.org/dams . Version 1. http://www.ambiotek.com/dams
Wint,G.R.W. and T.P. Robinson. (2007). Gridded livestock of the world 2007. FAO, Rome, 131 pp.

MODULE : Vulnerability to hazards

Ecosystems have a role to play in the mitigation of natural hazards. In Costing Nature we first calculate the environmental potential for hazards as an index varying from 0 to 1 globally. We then calculate human socio-economic exposure to this hazard and combine this with a measure of vulnerability to hazard in order to calculate risk where risk is the product of hazard exposure and vulnerability. Potential hazard mitigation services provided by nature for coastal inundation, floods,regulation services (e.g. drought) and landslides/soil erosion. These are then combined with risk to calculate realised hazard mitigation services as the minimum of the risk and potential hazard mitigation services indices.

We calculate an index of potential hazards taking into account cyclones, coastal inundation, landslides and soil erosion, floods and droughts. The potential cyclone hazard is calculated as the relative cyclone hazard frequency of Dilley et al. (2005). Potential flood hazard is calculated as proportional to the available water in each pixel (downstream cumulated rainfall minus actual evapotranspiration). Coastal inundation hazard is considered to be inversely proportional to elevation in the range 0-30 masl and in coastal areas (that is to say within 2000m of the coast). The coastal inundation hazard index (0-1) is comprised of sea level rise hazard (assumed to be uniform globally, gloabl relative Tsunami hazard (mapped by Mulligan, 2011 based on NGDC data) and global relative cyclone frequency as above. Potential hazards from landslides are assumed to scale with relative global mean upstream slope gradient. Hazard potential is then the mean of the cyclone hazard index, coastal inundation hazard index, landslide hazard index and flood hazard index.

Exposure to hazards is considered to scale with the relative human population, relative infrastructure, relative agriculture and relative GDP indices. Hazard exposure is then the product of hazard potential and hazard exposure. Vulnerability is assumed to scale inversely with combined GDP and infrastructure such that high GDP and infrastructure leads to lower vulnerability (even though they may also contribute to higher exposure). Risk is then the product of exposure and vulnerability.

Ecosystems provide a range of potential hazard mitigation services. These can derive from ecosystem processes *in situ* or elsewhere (e.g. upstream). The hazard mitigation services currently considered are landslide/erosion control, coastal protection, flood storage/mitigation, flow regulation). Landslide/erosion control is considered to be provided by the presence of vegetation, especially trees. Therefore the erosion control service is assumed to scale with the proportion of upstream land that is tree-covered. This tree cover index is also assumed to control the flow regulation service at a point. Flood control is assumed to be provided by water bodies, wetlands and floodplains, all of which provide storage capacity for flood waters. Thus the flood protection services provided to a particular point are assumed to scale with the upstream cover of water bodies, wetlands and floodplains. Coastal protection is assumed to be provided is coastal (within 2000m of the coast and from 0-30m above mean sea level) by mangroves and by wetlands in those areas.   Total potential hazard mitigation services is thus the sum of coastal protection, flood protection, flow regulation and soil erosion/landslide control services. Of course not all potential hazard mitigation services are realised since in many places the potential hazard or the actual risk are low. This the realised hazard mitigation services are calculates as the minimum of the potential hazard mitigation services and the actual risk.

National Geophysical Data Center / World Data Center (NGDC/WDC) Historical Tsunami Database, Boulder, CO, USA. (Available at http://www.ngdc.noaa.gov/hazard/tsu_db.shtml)

Dilley et al (2005) Natural Disaster Hotspots: A Global Risk Analysis.Version 1.0. Disaster Risk Management Series, No 5. World Bank, Washington DC

MODULE : Beneficiaries

Costing Nature provides spatially explicit assessments of realised ecosystem services according to the distribution of population, infrastructure and risk and thus inherently identifies a set of beneficiaries. Costing Nature also provides maps for those services realised by local beneficiaries (water provisioning, tourism, hazard mitigation) and those realised by global beneficiaries (carbon storage and sequestration for climate change mitigation).

MODULE : Opportunity costs

ALTERNATIVES

Costing Nature is a simple, data-based phenomenological model for ecosystem services, not a fully paramterised, physically based model. Therefore in applying scenarios for land use, land management and climate change we use techniques based on the identification of analogous areas to assign multi-ecosystem service values to areas that have undergone change. Analogous zones for land cover and use change are identified as follows: mean annual temperature and mean annual precipitation are zoned into 10 classes each which, when combined, can produce as many as 100 class combinations. Within each of these temperature and precipitation zones we identify pixels that have in the baseline the tree and herb cover values (within 5%) that are assigned in the scenario. The mean value in these areas for each service affected by land use and cover change is assigned to changed pixels in the respective zone. In this way the value of say carbon storage in an area converted from tree cover to pasture is assigned by identifying the mean value of all pasture pixels in the same climate zone (according to temperature and precipitation). This valkue is then assigned to all changed pixels.