Identifying species at extinction risk using global models of anthropogenic impact

HOWARD PETERS, BETHAN C. O’LEARY, JULIE P. HAWKINS and CALLUM M. ROBERTS
Environment Department, University of York, Heslington, York, YO10 5DD, UK

Abstract
The International Union for Conservation of Nature Red List of Endangered Species employs a robust, standardized approach to assess extinction threat focussed on taxa approaching an end-point in population decline. Used alone, we argue this enforces a reactive approach to conservation. Species not assessed as threatened but which occur predominantly in areas with high levels of anthropogenic impact may require proactive conservation management to prevent loss. We matched distribution and bathymetric range data from the global Red List assessment of 632 species of marine cone snails with human impacts and projected ocean thermal stress and aragonite saturation (a proxy for ocean acidification). Our results show 67 species categorized as ‘Least Concern’ have 70% or more of their occupancy in places subject to high and very high levels of human impact with 18 highly restricted species (range <100 km²) living exclusively in such places. Using a range-rarity scoring method we identified where clusters of endemic species are subject to all three stressors: high human impact, declining aragonite saturation levels and elevated thermal stress. Our approach reinforces Red List threatened status, highlights candidate species for reassessment, contributes important evidential data to minimize data deficiency and identifies regions and species for proactive conservation.

Keywords: aragonite, climate change, Conus, marine pollution, ocean acidification, Red List, sea surface temperature, thermal stress

Received 6 June 2014; revised version received 20 August 2014 and accepted 12 September 2014

Introduction
The International Union for Conservation of Nature (IUCN) Red List of Endangered Species was conceived in 1963 to evaluate the conservation status of species, focussing on those threatened with extinction. In 1994, standardized Categories and Criteria were introduced to closely define species extinction risk on which all assessments are now based (IUCN, 2012). Three Red List ‘threatened categories’ indicate levels of risk, namely: Critically Endangered, Endangered and Vulnerable with a fourth category, Near-Threatened, for those species liable to qualify for a threatened category in the near future. The category Data Deficient is attached to species with insufficient evidence to support a threatened listing, while Least Concern is for species deemed to be at no present risk. Five criteria, A to E, are used in Red List assessments to evaluate if a taxon belongs to a threatened category. Criterion A is based on the percentage decline in populations over 10 years or three generations, with larger declines reflecting a higher threat category; Criterion B on the biogeographical distribution of the taxon with reference to fragmentation, number of subpopulations, decline or fluctuations in occupancy and/or number of mature individuals, and/or habitat quality; Criterion C on the count of individuals in small populations with continuing declines, including within subpopulations; Criterion D on very small population counts of mature individuals and/or highly restricted Area of Occupancy and Criterion E on quantitative analysis of extinction risk over a defined time period (IUCN, 2012).

This categorization, supported by its codified criteria, has enforced uniformity on the evaluation process and enabled the Red List to be used to monitor trends in species’ status with the goal of ‘providing “information and analyses [...] in order to inform and catalyse action for biodiversity conservation’ (IUCN Red List Committee, 2013). Today the Red List is universally considered to be the most authoritative global conservation database available and the benchmark against which other indices of threat to species may be measured (Rodrigues et al., 2006; Hoffmann et al., 2008). It also functions as a performance assessment indicator for countries to manage their wildlife, including their legal obligations under international treaties (IUCN Red List Committee, 2013).

The success of the Red List is based on its identification of species approaching extinction (IUCN, 2013). However, we argue that this can steer conservation effort towards a reactive approach geared to species on the cusp of extinction, which for many may be too late.
Wide distributed taxa, in particular, are at risk of being overlooked in the belief that larger ranges offer greater survival opportunities. However, where there is widespread and continuing habitat degradation, as is common in both terrestrial and marine environments (Waycott et al., 2009; Krauss et al., 2010), fragmentation of habitat may not be recognized for years or even decades. This is particularly true in marine ecosystems, which are difficult to sample. Even though such areas may eventually contain only residual populations of a species, under Red List criteria the range may still be sufficient to qualify for ‘Least Concern’. Other Red List criteria focus on quantitative measures of population size. Although there is acknowledgement that populations are seldom measurable with accuracy and can be estimated, inferred, projected or suspected rather than based on direct observation (IUCN Standards & Petitions Subcommittee, 2010), there is a strong tendency to list species with limited information as Data Deficient. According to IUCN, listing species in nonthreatened categories should not deter conservation action (IUCN, 2012). However, as the purpose of the Red List is to focus conservation effort on threatened species, those not categorized as such are unlikely to garner the same support. In this article, we argue that use of geographical information on the distribution of human impacts, in conjunction with species’ range maps, offers enhanced assessment results with the advantage that biodiversity loss should be flagged well before the point that extinction looms.

Marine species are seriously under-represented on the Red List, making up 8459 species (9.8%) against 25 652 freshwater (29.9%) and 51 775 terrestrial (60.3%) (IUCN, 2013). One reason for this bias is the frequent difficulty in obtaining adequate data in the marine environment (McClanachan et al., 2012). We illustrate our expanded approach to risk assessment using a marine taxon, cone snails, which has recently undergone a comprehensive Red List assessment.

Cone snails are marine gastropod molluscs of the genus Conus. Recent advances in taxonomy have resulted in the reappraisal of many families and genera of gastropods (Bouchet & Rocroi, 2005) including the Conidae (Tucker & Tenorio, 2009; Bouchet et al., 2011). Because the revised systematics was not incorporated into the Red List at the time of assessment, to facilitate cross-referencing we refer to all cone snails as belonging to the genus Conus.

Cone snails occur throughout the world’s tropical seas where they live along coastal margins typically to 50 m depth but with some species found to below 500 m (Peters et al., 2013). Cone snails occupy diverse habitats and are commercially valuable in niche markets (Floren, 2003). They capture their prey of fish, molluscs or worms using complex neurotoxins (Olivera, 1997). These toxins possess exceptional biomedical potential that is the subject of research and development of novel drugs and therapies (Bingham et al., 2010). Additionally, cone shells are sought after by collectors and dealers and through this help support the livelihoods of the countless artisanal fishers who gather them (Floren, 2003; Rice, 2007; Hoorweg et al., 2009).

The Red List assessment of 632 species of Conus reveals large geographical variations in levels of diversity with concentrations of endemism and endangerment (IUCN, 2013; Peters et al., 2013). Twenty-five of the 41 globally threatened Conus species (61.0%) occur in the Eastern Atlantic, including all 14 assessed as Critically Endangered and Endangered. By contrast, across the vastness of the Indian and Pacific Oceans, home to 61.7% of cone snail species, just nine were listed as threatened with none in the Pacific. It is here, particularly the ‘Coral Triangle’ of Southeast Asia that the greatest concentration of Conus diversity occurs (Peters et al., 2013). Nevertheless, there is just a single Conus species, C. rawaiensis from Malaysia, listed as threatened on the Red List. In the Philippines, the global centre of marine biodiversity, not a single species has been assessed as threatened, despite the archipelago having experienced some of the most severe reef degradation seen anywhere in the world (Burke et al., 2011).

Shell collecting is only one of a number of threats faced by tropical marine molluscs including cone snails. Loss and damage to habitat from trawl and dredge fishing (Suuronen et al., 2012), and destructive fishing and coral mining are widespread in many regions (Chou, 2013). Pollution, both seaborne and from coastal development, also play their part. Marine molluscs including cone snails accumulate toxins such as lead, cadmium and mercury discharged into the marine environment from industrial and domestic effluents that are not only injurious to human health (Noël et al., 2011) but to the molluscs themselves (Sarkar et al., 2013). Other pollutants affecting their mortality include pesticides (Ray et al., 2013) and plastic litter (Aloy et al., 2011). Future threats from ocean acidification from combustion of fossil fuels combine with elevated sea-surface temperatures to exacerbate the impact on calcifying taxa such as molluscs and their larvae (Rodolfo-Metalpa et al., 2011; Gazeau et al., 2013; Wittmann & Pörtner, 2013). With the maximum life span of many cone snails extending beyond 20 years but with short generational time (Perron, 1986), future changes in ocean chemistry are likely to pose serious challenges (Gazeau et al., 2013).

With morphology being highly variable between cone snail species, for example shell size and thickness
(Röckel et al., 1995), the effects from anthropogenic pressures are also likely to differ between species. However, with mollusc larvae considered to be at particular risk from changes in ocean chemistry (Gazeau et al., 2013) variations between adult species may prove to be the lesser concern although further research is required in this area.

To test our hypothesis that Red List criteria can overlook many species at extinction threat resulting from the effect of human impacts, we analysed Red List data for all assessed species of Conus to compare its outcomes with our alternative method of determining risk to biodiversity. Our study uses indices of impact that do not equate with the Red List classification but inform or reinforce it. By using anthropogenic impact data compiled by Halpern et al. (Halpern et al., 2008), together with mapped future predictions of thermal stress and decreasing aragonite (CaCO\(_3\)) saturation across a 2030–2050 timeframe developed for the World Resources Institute ‘Reefs at Risk Revisited’ analyses by Burke et al. (Burke et al., 2011), we identified those areas of ocean occupied by cone snails that are likely to be subject to greatest threat. Although reaching beyond the ‘greater of three generations or 10 years population decline’ that define some Red List criteria (IUCN, 2012), the 2030–2050 timeframe used for projecting future thermal stress and aragonite saturation reflects an interval compatible with long-term marine conservation planning (Osmond et al., 2010). Adopting a holistic approach, we overlaid global species’ distribution data with geographical impact data to establish whether candidate species at risk had failed to fulfil the criteria for a Red List threatened category, as well as determining whether this new evidence would allow data deficient species to be reappraised and geographical areas at risk of highest species loss could be identified.

Materials and methods

To examine the overlap of all 632 Conus species’ ranges with variations in level of human impact now and into the future, and to measure the potential for biodiversity loss, a series of global maps were used: (i) known geographical range and bathymetric profile of Conus species using data from the IUCN Red List (IUCN, 2013) in association with oceanographic data from the General Bathymetric Chart of the Ocean (GEBCO, 2013); (ii) current anthropogenic impact data from Halpern et al. (Halpern et al., 2008) and (iii) predicted future thermal stress and decreased aragonite saturation from the World Resources Institute (Burke et al., 2011). ArcGIS version 10.1 with Python version 2.7 (Environmental Systems Research Institute) were used to analyse the data. All data were standardized onto 1° grid cells and projected to world cylindrical equal area.

Species distribution and bathymetric data sources

Red List geographical distribution data are calculated from known or estimated range size using two classifications measured in km\(^2\): Extent of Occurrence (EOO) and Area of Occupancy (AOO). EOO is the area within a polygon drawn around the boundary of the species’ range. AOO is the physical area in which the taxon is known to occur within the EOO. These data are further supported by digital maps derived from drawn ranges. To improve accuracy, we trimmed the AOO from these maps by excluding areas outside the known bathymetric range, the ‘Corrected AOO’ (GEBCO, 2013) but without extending into areas projecting beyond the limits of the AOO. Where species’ AOO overlapped the bathymetric contour, GEBCO data were accepted. However, for seven shallow water species in Cape Verde for which analysis indicated misalignment between species AOO and bathymetric contouring, visual inspection and adjustments to the Corrected AOO were made based on distribution alternatively described (Monteiro et al., 2004). The procedure is conservative from the perspective of extinction risk assessment since it assumes a species inhabits all of the area within its bathymetric range.

Marine environmental threat data sources

To assess the present day distribution of human impacts in the sea, Halpern et al. used a standardized, quantitative scoring method for the estimation of human impacts based on 17 ecosystem-specific drivers of change from anthropogenic forces (Halpern et al., 2008). Impacts were derived from a number of original sources but were classified into three major constituents: (i) pollution, including direct human, nonpoint inorganic and nutrient input; (ii) fishing: commercial, artisanal and demersal low and high by-catch and (iii) general impacts, including benthic structures (oil rigs), commercial fishing gear, ocean-based pollution (shipping lanes, ports) and species invasion (Halpern et al., 2008).

The Halpern et al. global model of human impacts, overlaid onto a 1° world grid, produced an average human impact score per grid cell in the range of zero to 50, which we classified according to the same impact categories they used: Very low: <1.4; Low: 1.4 to <4.95; Medium: 4.95 to <8.47; Medium high: 8.47 to <12; High: 12 to <15.52; Very high: 15.52+.

Although Halpern et al. admitted that some ecosystem data were variable in quality and that some historical effects may still continue even though their drivers were no longer present, they considered their results the best current estimate of anthropogenic impacts (Halpern et al., 2008). An alternative from Reefs at Risk Revisited (Burke et al., 2011) was considered but found unsuitable as large areas of ocean occupied by cone snails fell outside its geographical scope. However, their global dataset of projected ocean warming (based on predicted elevated sea surface temperatures) and acidification (using predicted aragonite saturation levels as a proxy) from greenhouse gas emissions for 2030 and 2050 were suitable.

As ocean acidification increases, pH levels decline along with aragonite saturation, resulting in reduced coral growth and shell-building capability (Fabry et al., 2008). Future
aragonite saturation was modelled by Burke et al. using data developed at the Carnegie Institution Department of Global Ecology at Stanford University (Cao & Caldeira, 2008). Saturation states at various atmospheric CO2 stabilisation levels were based on a global climate model with saturation of 380 ppm for 2005 and 450 ppm and 500 ppm for 2030 and 2050 respectively. These levels are more optimistic than the IPCC A1B ‘business as usual’ scenario (Burke & Reytar, 2011; Burke et al., 2011). Converting saturation states to threat scores was based on suitability for coral growth determined from Guinotte et al. (Guinotte et al., 2003) with some minor adjustments (Burke et al., 2011). We adopted the same scoring groups as the authors with the exception that for the high score we subdivided it into High and Very High, as follows:
Low: \(<3.25\); Medium: 3 to \(<3.25\); High: 2.6 to \(<3\); Very High: \(<2.6\)

Elevated sea-surface temperatures not only increase mortality rates of many marine species including molluscs, but also exacerbate the deleterious effects of acidification (Rodolfo-Metalpa et al., 2011). Future thermal stress was modelled by Burke et al. using accumulated degree heating months (DHM) from the Geophysical Fluid Dynamics Laboratory general circulation models (Donner, 2009). The future thermal stress variable represents the frequency, as a percentage of years within a decade that the DHM exceeds the coral bleaching threshold represented by NOAA Bleaching Alert Level 2, i.e. conditions that can cause severe coral bleaching and/or mortality, adjusted for historical sea surface temperatures (SST). Burke et al. classified areas predicted to experience a Level 2 alert at a frequency of 25–50% during the decade as medium threat, with \(>50\%\) classified as high threat (Burke et al., 2011). For reporting and visual display purposes, scores were grouped by the authors into the following impact categories, which we adopted with the exception of the high score that we subdivided into High and Very High, as follows:
Low: \(<25\%\); Medium: 25 to \(<50\%\); High: 50 to \(<75\%\); Very High: 75–100%

The average cell impact score for both future threats were calculated by intersecting the data sources with a 1° world grid. Cells identified with no impact score, caused by the proximity of land mass creating voids in the source raster data, were completed where possible by averaging the scores from surrounding marine cells.

**Geographical information systems (GIS)**

Spatial and temporal variability in biodiversity are important indicators of ecosystem function (Cardinale et al., 2006) and a proxy measure of susceptibility to disruption from anthropogenic forces in species-rich regions. To determine the composition of Conus species diversity within regions of exceptional richness a global species richness map was constructed using the bathymetrically corrected AOO maps for each of the 632 species.

To identify levels of threat from which to infer population declines, we examined current anthropogenic impacts for each grid cell in which at least one Conus species was known to occur. To determine taxa at greatest threat we calculated the percentage occupancy of High and Very High impact cells for every species across its entire known distribution range.

There is a greater risk of extinction for species that are geographically restricted (Roberts et al., 2002; Harnik et al., 2012). Areas with large clusters of such species, such as those typically found in and around islands and archipelagos isolated from continental land masses, can potentially experience higher rates of species loss (Roberts et al., 2002). Range-rarity is a measure of a species’ endemism based on the extent of its geographical distribution. By aggregating the individual range-rarity scores for all species that coexist within a predefined area such as a grid cell, the relative importance of that area as a centre of endemism, together with the species within it, can be identified. To more easily identify such areas, we calculated the reciprocal of each species’ Corrected AOO to emphasize those species with the smallest range (Roberts et al., 2002). We mapped range-rarity as a function of the sum of the range-rarity for all species present in each grid cell. To accommodate decimal place limits in ArcGIS and ease of reporting, we multiplied all range-rarity scores by \(10^4\).

To identify high-threat areas supporting the largest concentrations of range-rare species that could potentially result in the greatest loss of Conus diversity at a regional level, we examined the top 10% of grid cells by summed range-rarity score. We overlaid these cells with scores for each of current anthropogenic impact and projected aragonite saturation and thermal stress (in 2030 and 2050 for both) for each grid cell in which at least one Conus species was known to occur.

**Results**

**Species richness**

A total of 632 species of cone snail were distributed across 4,033 grid cells, all within the tropics and subtropics to approximately 38° north and south (Fig. 1a).

Species richness was found to be highly uneven, being greatest across south-east Asia and the Coral Triangle, peaking in the Philippines, and then remaining high in an arc south to southeast through Indonesia, Papua New Guinea, Solomon Islands, New Caledonia, Vanuatu and east to Fiji (Fig. 1a).

The highest levels of richness (cells containing 126 species and above) are geographically limited, occupying just 3.5% of the total area of Conus distribution. By contrast, low richness areas (\(<25\) species per grid cell) make up 43.7% of the total area occupied by Conus (Fig. 2). The cell with the highest richness is in the Philippines and contains 188 species.

**Species’ exposure to human impacts**

Current human impact scores from Halpern et al. for cells occupied by Conus species (Fig. 1b) illustrate the prevalence of High and Very High impact areas.
There were 664 High impact cells (16.5%) in which cone snails occurred and 1013 Very High impact (25.1%), with the remainder 2356 (58.4%) at a lower level of risk. No cells occupied by cone snails were classified at Very Low impact. Figures S1 and S2 show numbers of cells and species, respectively, by level of impact. Of 632 species of *Conus* globally, 22 occur entirely in cells of Very High impact with a further 34 similarly restricted to cells of High and Very High impact. These 56 species should be considered as candidates for conservation priority. However, since range size is also a determining factor, those with the smallest range would probably be extirpated before others under identical scenarios. Of these 56 species, 26 had a range of less than 10 km² (46.4%), 16 had a range 10–100 km² (28.6%) and 14 > 100 km² (25.0%). Table S1 lists the 56 species most at risk from impacts sorted by range size and Red List status.

Thirty-nine of the 56 species (69.6%) are found in the Eastern Atlantic, ten in the Indo-Pacific and seven in the Western Atlantic. There was a mean occupancy of 2.3 cells, with 36 (64.3%) species each occupying just a single cell. This concentration in the Eastern Atlantic was in line with expectations since the region had been classified as a centre for threatened endemic cone snails (Peters et al., 2013). From the 56 species subject to High and Very High impact, 27 were already categorized as Threatened or Near Threatened, however, eight were Data Deficient (DD), and 21 were Least Concern of which 18 occurred within an area <100 km² (Table S1).
Most \textit{Conus} species had at least part of their geographical range overlapping High and Very High impact cells. As the percentage of overlap increases, the risk of extinction can be expected to rise. Figure 3 shows the percentage overlap of \textit{Conus}' ranges with High and Very High impact regions. Two hundred and sixty-five species (42%) have half or more of their range overlapping High and Very High impact regions. Of these, the 56 species discussed above are at the highest ranking of risk since their entire ranges lie in High and Very High impact cells (Fig. 3). However, we used the three groupings immediately below this level that together form 70% or more of their cell occupancy in High and/or Very High impact regions, 87 (75.7%) are categorized on the Red List as either Least Concern or Data Deficient. Over half, 44 (50.6%) occur in the Indo-Pacific, followed by 23 in the Western Atlantic (26.4%), 19 in the Eastern Atlantic (21.8%) and one in the Eastern Pacific (1.1%) (Fig. 4).

Whereas it is true that Indo-Pacific species are on average wider ranging than species from other ocean basins and therefore may be considered to have enhanced extinction resilience [Indo-Pacific species have a mean Corrected AOO of 933 971 km² ± SD: 1 705 500 \((n = 390)\), Eastern Pacific 91 277 km² ± SD: 72 367 \((n = 31)\), Western Atlantic, 90 751 km² ± SD: 212 276 \((n = 113)\) and Eastern Atlantic 3627 km² ± SD: 18 965 \((n = 98)\)], the Indo-Pacific also has more range-restricted species. There are 97 species in the Indo-Pacific with a Corrected AOO of <10 000 km², three in the Eastern Pacific, 47 in the Western Atlantic and 93 in the Eastern Atlantic. Hence, there may be more species at risk in the Indo-Pacific than the Red List has revealed.

Range-rarity and endemism

Summed range-rarity scores identify which geographical regions are likely to be home to the greatest density of endemic \textit{Conus}. Cells with very high summed range-rarity values represent centres of endemism and occur in the Eastern Atlantic including Cape Verde, Senegal and Angola. Others include the Eastern Cape, the Horn of Africa and the Arabian Gulf, New South Wales and various island groups of the Pacific Plate; also the Gulf of Mexico and the Caribbean (Fig. 1c). We found no significant correlation between summed range-rarity and species richness of cells [Pearson’s \(r = 0, P > 0.05, n = 3055\)]. Range-rarity is important since high densities of restricted-range species, subject to severe levels of anthropogenic threat, could result in exceptional biodiversity loss.

The cells with the top 10% range-rarity scores are shown on Figure 1c at the highest level (5%) and the second highest (6–10%). To identify centres of endemism at greatest threat we adopted these top 10% of cells as an arbitrary cut-off (resulting in 411 of 4033 cells, the extra 8 cells due to equal range-rarity scores at the cut-off point). These cells, classified with scores from each of five threat scenarios are shown as: anthropogenic impacts (Fig. 5a), aragonite saturation at 2030 and 2050 (Fig. 5b and 5c) and thermal stress at 2030 and 2050 (Fig. 5d and 5e).

Cells that were void of data were assigned scores based on the average of the surrounding cells.
However, although all cells for human impact data were successfully included within our analysis (Fig. 5a), 36 cells for projected aragonite concentration in 2030 and 2050, and seven cells for projected thermal stress in 2030 and 2050 of the total 411 were excluded owing to all surrounding cells also being void.

Figure 5 illustrates the potential for a significant loss of biodiversity under each of the five threat scenarios, and in particular shows the projected deterioration between the 2030 and 2050 scenarios for acidification and elevated sea-surface temperatures.

Regions with high levels of endemism are at much greater risk of multiple species loss. This is manifest in the Eastern Atlantic where the high incidence of endemism has resulted in a very high ratio of threatened species (Peters et al., 2013). Such regions would benefit most from targeted conservation.

Discussion

We found 56 species of *Conus* occurring wholly in areas of High and Very High human impact, of which 21 were categorized on the Red List as Least Concern with a further eight as Data Deficient. Extending the approach to a second tier of exposure to human impacts - species with 70–99% of their range overlapping areas of High and Very High impact - we discovered an additional 59 species at risk, of which 46 had been categorized as Least Concern and 12 as Data Deficient in the Red List (IUCN, 2013). Taken together, 75.6% of species exposed to the highest levels of anthropogenic threat are unlikely to be earmarked for conservation.

Geographical mapping of summed range-rarity scores for *Conus* revealed many centres of endemism. Some already face high levels of human impact, while others will come under increasing threat as the oceans warm and acidify. The importance of these analyses is that they highlight worrying gaps in the Red Listing process. Although Eastern Atlantic centres of endemism were reflected in Red List species assessments, we have flagged up other regions with the potential for rapid biodiversity loss, and therefore of great conservation concern where timely intervention could yield large benefits. For example, the Philippines is identified as being at risk. This is the global centre of *Conus* diversity (Fig 1a) and faces some of the most severe habitat degradation in the world from impacts of blast fishing, pollution and nutrient loading among others (Burke et al., 2011). The majority of cone snails in the Philippines live in association with coral reefs (Röckel et al., 1995) and it is precisely these areas that are subject to the most intense destructive forces. Nevertheless, the Philippines has no threatened *Conus* species on the Red List. This is also true for many regions of Southeast Asia where more than 100 species co-exist, including parts of Indonesia and the Solomon Islands.

Data deficiency is a major hindrance to conservation planning. Lack of knowledge is often a function of rarity, in terms of both abundance and range size (Brito, 2010), potentially denying many vulnerable species the opportunity for targeted and timely action. Data deficiency is also more likely in regions with lower levels of economic development (Butchart et al., 2010; McGrooch et al., 2010) where natural resource management
Fig. 5 Distribution of centres of Conus endemism under threat. This shows the cells containing the top 10% ($n = 411$) of summed range-rarity scores classified under different threat scenarios: (a) anthropogenic impacts\(^1\); (b) aragonite saturation 2030 (450 ppm)\(^2\); (c) aragonite saturation 2050 (500 ppm)\(^3\); (d) thermal stress 2030\(^2\); (e) thermal stress 2050\(^3\).\(^4\)Halpern et al. (2008), \(^5\)Burke et al. (2011).
and data acquisition expertise are scarce. Data Deficient taxa are often suspected of being at risk but they lack sufficient evidential data for categorization to threatened status. Recent research modelling life-history and environmental data to non-Data Deficient amphibians and applying it to Data Deficient species showed the latter to be at greater risk than those fully assessed (Howard & Bickford, 2014). For cone snails, 87 species (13.8% of all 632 assessed) are categorized as such on the Red List of which 75 (86.2%) occur in the Indo-Pacific (Peters et al., 2013). A recent analysis reveals how data deficiency can grossly devalue Red List statistics with 26% of marine invertebrates assessed as Data Deficient, including 76% of 195 cuttlefishes and 35% of 247 marine lobsters (Kemp et al., 2012). In this analysis, 20 Indo-Pacific species of Conus assessed as Data Deficient had at least 70% of their habitat overlapping regions with High or Very High human impact.

Estimating population sizes for marine taxa in particular is problematic, except in specific circumstances, such as those occurring exclusively in the observable littoral zone to 30 m depth. In the absence of population data, Red List criteria for threatened status are based on range size. Criterion B entry point provides for a listing of vulnerable status if the AOO is <2000 km² together with two choices from a menu of three: severe fragmentation, declining AOO or EOO, or extreme fluctuations in AOO or EOO (unlikely for molluscs). For Endangered categorization the AOO must be <500 km² and for Critically Endangered <10 km² (IUCN, 2012). For many marine taxa, estimating range sizes to this degree of precision can be daunting, and for shallow water invertebrates such as molluscs there is a tendency towards a patchy rather than uniform distribution often resulting in overestimation (Nelson et al., 1991). Species whose range sizes have been overestimated may fall outside the criteria and escape being placed at risk. Of 67 species of Conus categorized as threatened or near threatened, 43 (64.2%) had been overestimated on AOO compared with our results corrected according to their known depth range.

This tendency to offer a more optimistic picture extends to the role of experts in reviewing draft assessments. This element is critical to the process and deservedly bestows authority on the Red List (Rodrigues et al., 2006). It is undertaken with rigour; however, it is also prone to human bias, especially with commercially exploited species. The author has witnessed reluctance by some to list species that are considered rare, even when they occur in habitats recognized to be under high levels of stress.

It has been argued that IUCN Red List standards and procedures are too prescriptive with excessive rigidity in the criteria used to determine the assessment category and that greater weight should be placed on qualitative judgements, such as examining current population stability, rather than quantitative scoring against historical abundance (Mrosovsky, 2003). Other attributes, including larger body size which increases susceptibility to targeted capture, and trophic category that reflects upon ecosystem structure and resilience, have both been found to influence vulnerability, particularly when range-size and endemism are accounted for (Bender et al., 2013). Mrosovsky was excoriating in his critique of the Red List and, using turtles as examples, argued that the assessment process had often led to an over-pessimistic view of species’ status that debased categorization, with Critically Endangered in particular being overused or misused. We believe no standard system is perfect but some imperfection has to be weighed against a methodology that can also be applied, managed and implemented effectively by personnel unfamiliar with the taxa, and who can train and support those who are expert without an unwieldy and expensive bureaucracy. In this the Red List has been remarkably successful (Rodrigues et al., 2006). Whereas Mrosovsky argued that reliance solely on quantitative data resulted in species’ extinction risk being overstated, our findings suggest that for some wider ranging species occurring over large areas with unknown quality of habitat, risk may be understated. However, this criteria-based evaluation of species approaching their end-point focuses primarily on those considered the most deserving cases where conservation is tinged with desperation. We believe that a broader perspective is needed to support and enhance the Red List; one that addresses potential biodiversity loss on a wider scale, and that can have greater consequences for decisions about timely conservation intervention.

The standard IUCN Red List assessment demands research into species distribution, habitat, threats, and where possible, population estimates, with results endorsed through peer-review. This methodology is regulated through a uniform, criterion-based approach. Our strategy, although not directly comparable, takes a broader holistic approach that identifies some species categorized through Red List criteria as Least Concern or Data Deficient as being at potential risk. This includes species with high percentage occupancy of high impact areas falling outside Red List AOO thresholds. Furthermore, for marine species, the AOO may be smaller when corrected through its bathymetric profile than that estimated for the Red List, taking it outside threatened category thresholds. This broad quantitative assessment of the degree of exposure to human threat that a species is likely to face affords much stronger grounds for an at-risk assessment.
Our approach is particularly appropriate for small, sessile or semisessile organisms including many of the invertebrates. Suitable Red List assessed taxa, for example, could include scleractinian corals, where elevated sea-surface temperatures and general anthropogenic disturbance have resulted in serious declines (Carpenter et al., 2008; IUCN, 2013). However, with appropriate spatial data, many nonmarine species such as crayfish, threatened by severe habitat loss/degradation, water pollution and overexploitation (IUCN, 2013; Collen et al., 2014), and amphibians, subject to similar stressors (Stuart et al., 2004; IUCN, 2013) could also benefit. This application of spatial anthropogenic threat data should be considered in the assessment of many large groups, particularly from the invertebrates and other nonmigratory species. Nevertheless, although valuable across a wide range of such taxa, threat data are very general and in some cases there may be specific mapped threats highly relevant to the taxon that should be subject to detailed investigation for any assessment.

Geographical data on human impacts, which are increasingly available, can we contend, add true value to assessment results that would otherwise be data poor. By using such data we have been able to reveal new species under threat that can be recommended for re-assessment. This approach enables early warnings to be sounded on potential population declines, particularly for range-restricted species and areas with high levels of endemicism, providing regional authorities with data for proactive conservation management. It also offers important evidential data to species assessed as Data Deficient. Reducing incidence of data deficiency in the Red List should be of concern to all assessors. Additionally, for those species already listed as threatened, impact data reinforce existing categorization and strengthen its rationale, as well as provide additional evidence for recategorization including upgrade from near-threatened to threatened status.

Finally, we should add that the authors are committed supporters of the Red List and consider it an essential tool in the armoury of conservation science. This study is intended to complement its proven methodology and enable a longer term approach to be taken for the many species that could eventually qualify under Red List criteria if left unattended.

Acknowledgements
We are grateful to the U.K. Natural Environment Research Council (NERC) for funding this research. We also gratefully acknowledge the support of Kent Carpenter at IUCN Global Marine Species Assessment for his technical assistance; Mark Westneat, Audrey Aronovsky, Sarah Kim and Beth Sanzenbacher at the Biodiversity Synthesis Center, Chicago for their organization of the Conus synthesis workshop at the Field Museum in Chicago; Philippe Bouchet, José Coltro, Tom Duda, Alan Kohn, Eric Monnier, Hugh Morrison, Ed Petuch, Guido Poppe, Gabriella Raybaudi-Massilia, Sheila Tagaro, Manuel Jiménez Tenorio, Stephan Veldsman and Fred Wells for volunteering their time and expertise during the assessment and at the synthesis workshop; Monika Böhm, Heather Harwell, Andrew Hines, Suzanne Livingstone, Jonnell Sanciangco and Mary Seddon for facilitating at the synthesis workshop; Mike Filmer for helping to resolve the many taxonomic issues; Bryce Stewart for his critical review; Hannah Cubaynes, Zarozinia Sheriff and all the interns who assisted with species research; Klaus & Christina Groh of ConchBooks for use of images and maps for the Red List; Mia Theresa Comeros and Angela Goodpaster for their work on the Red List maps and Caroline Pollock and Janet Scott of the IUCN Red List Unit for bringing the assessment to publication.

References
Aloy AB, Vallee BM, Junio-Me, Mora C (2010) Increased plastic litter cover affects the foraging activity of the sand-tidal gastropod Nassarius pullus. Marine Pollution Bulletin, 62, 1772–1779.
Bender MG, Floeter SR, Mayer FP et al. (2013) Biological attributes and major threats as predictors of the vulnerability of species: a case study with Brazilian reef fishes. Oryx, 47, 259–265.
Bingham J-P, Mitsunaga E, Bergerson ZL (2010) Drugs from slugs: past, present and future perspectives of omega-conotoxin research. Chemico-Biological Interactions, 183, 1–18.
Bouchet P, Rocroi J-P (2005) Classification and nomenclator of gastropod families. Malacologia, 47, 1–397.
Bouchet P, Kantor YI, Sysoev A, Puillandre N (2011) A new operational classification of the Conoidea (Gastropoda). Journal of Molluscan Studies, 77, 273–308.
Brito D (2010) Overcoming the Linnaean shortfall: data deficiency and biological survey priorities. Basic and Applied Ecology, 11, 709–713.
Burke L, Reyart K (2011) Reefs at Risk Revisited: Technical Notes on Modeling Threats to the World’s Coral Reefs Reefs at Risk Project Purpose. World Resources Institute, Washington, DC.
Burke L, Reyart K, Spalding M, Perry A (2011) Reefs at Risk Revisited. World Resources Institute, Washington, DC.
Butchart SHM, Walpole M, Collen B et al. (2010) Global biodiversity: indicators of recent declines. Science (New York, NY), 328, 1164–1168.
Cao L, Caldeira K (2008) Atmospheric CO2 stabilization and ocean acidification. Geophysical Research Letters, 35, L19609.
Cardinale BJ, Srivastava DS, Duffy JE, Wright JP, Downing AL, Sankaran M, Jouseau C (2008) Effects of biodiversity on the functioning of trophic groups and ecosystems. Nature, 445, 989–992.
Carpenter KE, Aebischer N, Sankaran M, Jouseau C (2008) Global biodiversity: indicators of recent declines. Science (New York, NY), 321, 560–563.
Chou LM (2013) Science and management of Southeast Asia’s coral reefs in the new millennium. Galaxea, Journal of Coral Reef Studies, 15, 16–21.
Collen B, Whittle F, Dyer EE et al. (2016) Global patterns of freshwater species diversity, threat and endemism. Global Ecology and Biogeography, 25, 40–51.
Donner SD (2009) Coping with commitment: projected thermal stress on coral reefs under different future scenarios. PLoS ONE, 4, e5712.
Fabry VJ, Seibel BA, Feely RA, Orr JC (2008) Impacts of ocean acidification on marine fauna and ecosystem processes. ICES Journal of Marine Science, 65, 414–432.
Floren AS (2003) The Philippine Shell Industry With Special Focus on Maتان用 Tol, Cebu. The Philippines Coastal and Fisheries Management Information Centre, Available at: www.oneocean.org/download/db_files/philippine_shell_industry. pdf (accessed 30 September 2013).
Gazeau F, Barker LM, Comeau S et al. (2013) Impacts of ocean acidification on marine shelled molluscs. Marine Biology, 160, 2207–2245.
GECO (2013) General bathymetric chart of the oceans. GECO 08 Grid. Available at: https://www.bdoc.aodc.org/data/online_delivery/geco/ (accessed 21 September 2012).
Guinotte JM, Buddemeier RW, Kleypas JA (2003) Future coral reef habitat marginality: temporal and spatial effects of climate change in the Pacific basin. Coral Reefs, 22, 551–558.
Halpern BS, Wallbridge S, Selkoe KA et al. (2008) A global map of human impact on marine ecosystems. Science (New York, NY), 319, 948–952.

Harnik PG, Simpson C, Payne JL. (2012) Long-term differences in extinction risk among the seven forms of rarity. Proceedings of the Royal Society B: Biological Sciences, 279, 4896–4976.

Hoffmann M, Brooks TM, da Fonseca GAB et al. (2008) Conservation planning and the IUCN Red List. Endangered Species Research, 6, 113–125.

Hoorweg J, Versleijen N, Wangila B, Degen A (2009) Income diversification and fishing practices among artisanal fishers on the Malindi-Kilifi coast. In: Advances in Coastal Ecology. People, Processes and Ecosystems in Kenya (ed Hoorweg J, Muthiga N), African Studies Collection 20. African Studies Centre, Leiden.

Howard SD, Bickford DP (2014) Amphibians over the edge: silent extinction risk of Data Deficient species (ed Ferrier St). Diversity and Distributions, 20, 837–846.

IUCN (2012) IUCN Red List Categories and Criteria: Version 3.1 (2nd edn). IUCN, Gland, Switzerland and Cambridge, UK.

IUCN (2013) IUCN Red List of Threatened Species. The IUCN Red List of Threatened Species Version 2013.2. Available at: http://www.iucnredlist.org. (accessed 30 September 2013).

IUCN Red List Committee (2013) The IUCN Red List of Threatened Species™ Strategic Plan 2013–2020. Version 1.0. Prepared by the IUCN Red List Committee, Gland, Switzerland.

IUCN Standards and Petitions Subcommittee (2010) Guidelines for Using the IUCN Red List Categories and Criteria. Version 8.0. Prepared by the Standards and Petitions Subcommittee in March 2010, Gland, Switzerland.

Kemp R, Peters H, Carpenter KE, Obura D, Polidoro B, Richman N (2012) Marine invertebrate life. In: Spindloe: Status and Trends of the World’s Invertebrates (eds Collen B, Böhm M, Kemp R, Baillie JEM), pp. 34–45. Zoological Society of London, United Kingdom.

Krauss J, Bommarco R, Guardiola M et al. (2010) Habitat fragmentation causes immediate and time-delayed biodiversity loss at different trophic levels. Ecology Letters, 13, 597–605.

McClenachan L, Cooper AB, Carpenter KE, Duval NK (2012) Extinction risk and bottlenecks in the conservation of charismatic marine species. Conservation Letters, 5, 73–80.

McGeoch MA, Butchart SHM, Spear D et al. (2010) Global indicators of biological invasion: species numbers, biodiversity impact and policy responses. Diversity and Distributions, 16, 95–108.

Monteiro A, Tenorio MJ, Poppe GT (2004) A Conchological Iconography. The Family Conidae. The West African and Mediterranean Species of Conus. ConchBooks, Hackenheim, Germany.

Mrosovsky N (2003) Predicting extinction: fundamental flaws in IUCN’s Red List system, exemplified by the case of sea turtles. Available at: http://members.seaturtle.org/~mrosovsky/ (accessed 30 September 2013).

Nelson DM, Irlandi EA, Settle LR, Monaco ME, Costa-Clements L (1991) Distribution and Abundance of Fishes and Invertebrates in Southeast Estuaries. ELMR Rep. No. 9. NOAA/NOES Strategic Environmental Assessment Division, Silver Spring, MD.

Noel L, Testu C, Chafey C, Velge P, Guerin T (2011) Contamination levels for lead, cadmium and mercury in marine gastropods, echinoderms and tunicates. Food Control, 22, 433–437.

Olivera BM (1997) E.E. Just Lecture. 1996. Conus venom peptides, receptor and ion channel targets, and drug design: 50 million years of neuropharmacology. Molecular Biology of the Cell, 8, 2101–2109.

Osmond M, Airame S, Caldwell M, Day J (2010) Lessons for marine conservation planning: a comparison of three marine protected area planning processes. Ocean & Coastal Management, 53, 41–51.

Perron FE (1986) Life history consequences of differences in developmental modes among gastropods in the genus Conus. Bulletin of Marine Science, 39, 485–497.

Peters H, O’Leary BC, Hawkins JP, Carpenter KE, Roberts CM (2013) Conus: first comprehensive conservation red list assessment of a marine gastropod mollusc genus. PLoS ONE, 8, e83353.

Ray M, Bhunia AS, Bhunia NS, Ray S (2013) Density shift, morphological damage, lysosomal fragility and apoptosis of hemocytes in Indian molluscs exposed to pyrethroid pesticides. Fish & Shellfish Immunology, 35, 499–512.

Rice T (2007) A Catalog of Dealers’ Prices for Shells; Marine, Land and Freshwater (23rd edn). Of Sea and Shore Publications, Port Gamble, WA.

Roberts CM, McClean CJ, Veron JEN et al. (2012) Marine biodiversity hotspots and conservation priorities for tropical reefs. Science (New York, NY), 295, 1280–1284.

Röckel D, Korn W, Kohl AJ (1995) Manual of the Living Conidae, Vol I. Verlag Christa Hemmen, Wiesbaden, Germany.

Rodolfo-Metalpa R, Houdeëuf F, Tambutté É et al. (2011) Coral and mollusc resistance to ocean acidification adversely affected by warming. Nature Climate Change, 1, 308–312.

Rodrigues ASL, Pilgrim JD, Lamoreux JF, Hoffmann M, Brooks TM (2006) The value of the IUCN Red List for conservation. Trends in Ecology & Evolution, 21, 71–76.

Sarkar A, Bhagat J, Ingole BS, Rao DP, Markad VL (2013) Genotoxicity of cadmium chloride in the marine gastropod Nerita chamaeleon using comet assay and alkaline unwinding assay. Environmental Toxicology. doi: 10.1002/tox.21883. [Epub ahead of print].

Stuart SN, Chanson JS, Cox N a, Young BE, Rodrigues ASL, Fischman DL, Waller WR (2004) Status and trends of amphibian declines and extinctions worldwide. Science (New York, NY), 306, 1783–1786.

Suuronen P, Chopin F, Glass C, Lakkereborg S, Matsuhashi Y, Queirolo D, Rihan D (2012) Low impact and fuel efficient fishing—looking beyond the horizon. Fisheries Research, 119–120, 135–146.

Tucker JK, Tenorio MJ (2009) Systematic Classification of Recent and Fossil Conidae Gastropleons. Conchbooks, Hackenheim.

Waycott M, Duarte CM, Carruthers TJ et al. (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceedings of the National Academy of Sciences of the United States of America, 106, 12377–12381.

Wittmann AC, Partner H-O (2013) Sensitivities of extant animal taxa to ocean acidification. Nature Climate Change, 3, 995–1001.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Conus species occurring wholly in 1° grid cells at High and Very High impact only.

Table S2. Conus species occurring in 1° grid cells with 70–99% of their occupancy in High and Very High impact areas.

Figure S1. Analysis of 1° grid cells occupied by Conus species by predicted level of human impact.

Figure S2. Exposure to human impacts for Conus species.