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A Bat Monitoring Network for Global Change in the Anthropocene: Now or Never

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The Biodiversity Crisis

At local, regional, and global scales, biodiversity and the services that it provides to people are being threatened by anthropogenically induced factors such as climate change, land use change, invasive species, and the interactions among them. Moreover, the distribution of negative effects on biodiversity from such global change drivers will not be homogeneous throughout all regions of the planet, and many areas that currently harbor high biodiversity will likely suffer disproportionately higher rates of habitat loss and fragmentation, as well as continued degradation in the coming decades of this century.

Humans have a long history of modifying natural landscapes and converting them to uses (e.g., croplands, pastures, urban areas, industrial developments) that serve the welfare of society, at least in the short term. Nonetheless, the extent of land use modification has become so pervasive and severe that some have come to recognize the last few hundred years, especially those associated with the industrial revolution and the mechanization of agriculture, as the Anthropocene (Steffan et al. 2003; Zalasiewicz et al. 2010). Similarly, recognition of the emerging dominance of anthropogenically modified landscapes -- anthromes -- suggests the ubiquitous nature of human-dominated landscapes that have emerged over the last few centuries (Ellis and Ramankutty, 2008; Ellis et al. 2010). We now live in a world in which wildlands occupy less than a quarter of the area of terrestrial biomes (Figure 1) and are in rapid decline.

Throughout much of the world, human populations continue to increase, as does the per capita use of resources. By 2050, the size of the human population is projected increase by 2.3 billion individuals (UNDESSA 2007). For global food production to meet this demand, it must increase by 70% (FAO, 2010). Although some of this required increase in production will be attained by cultivating crops with higher yields, including use of genetically modified organisms, a substantial portion of the required increase will necessitate the conversion of natural areas to agricultural lands. For energy supplies to meet the demands of a burgeoning human population, energy production must increase by 100% (Sheffield, 1999), with a substantial quantity potentially associated with biofuel production, causing additional reduction in the extent of natural areas or diminishing the allocation of arable land to food production. In general, the effects of decreasing the amount of habitat and increasing the fragmentation of habitat are clear from theoretical and empirical perspectives (Pimm and Raven, 2000; Barbault and Sastrapradja, 1995): population sizes decrease and species go extinct.

Climate change and increasing climate variability will alter the geographic distribution of critical environmental factors (e.g., temperature, precipitation), as well as the frequency, intensity, and scale of disturbances (e.g., cyclonic storms, droughts), all of which affect the distribution and abundance of organisms (Parmesan et al., 2000), as well as the interactions among them (Gilman et al., 2010). By some estimates, climate change alone could contribute to the extinction of approximately 25% of the species in some groups of organisms, such as vertebrates and plants (Malcolm et al., 2006). In part, this may occur because new combinations of environmental characteristics may emerge more rapidly than will the ability of some species to adapt to them. Alternatively, no-analog communities (i.e., novel combinations of species compared to current communities) will develop in which biotic interactions may enhance extinction rates (Williams and Jackson, 2008). Moreover, species occupying high elevation habitats, especially those in the Tropics, which have heretofore been buffered from the effects of humans because of their inaccessibility and ruggedness, may be particularly vulnerable to extinctions as current high-elevation habitats will shrink in extent and the species that are high elevation specialists will suffer higher extinction rates than their low elevation counterparts (Colwell et al., 2008). Currently, such mountainous areas enjoy particularly high species richness and are inhabited, especially at higher elevations, by micro-spatial species (i.e., those with small geographic distributions), which are characterized by high extinction probabilities (Andelman and Willig, 2003). Taken together, these factors strongly suggest that the world's biota will become increasingly subjected to threats – direct and indirect – associated with human activities. Consequently, the biodiversity crisis will likely become even more severe in the future, and may represent one of the most important long-term threats to human welfare, via effects on ecosystem services, that must be confronted by society in the 21st Century.

Biological Indicators and Bats

Effective biological indicators should reflect the responses of a range of taxa beyond the indicator taxon, and should do so at the level of populations and communities. Additionally, these indicators should herald alterations in ecosystem function and associated services derived by humans. Importantly, the members of the indicator taxon should be responsive to the kinds of environmental changes or stresses that are anticipated in the future, and should be able to capture successes in response to management, conservation, and policy initiatives. Finally, biological indicators should be relatively easy to monitor over space and time.

The taxonomy of the bats is well understood, and the group is species rich and cosmopolitan in distribution. The slow reproductive rate of bats (fecundity of no more than 1-3 young per year per female) enhances the likelihood that changes in abundance in response to stressors can be quite rapid, thereby acting as an early indicator for other taxa (i.e., enhanced mortality cannot be easily overcome because of limits established by fecundity). Moreover, bats are relatively easy to capture via mist netting, and advances in technologies associated with acoustic monitoring (Sherwin et al. 2000; Russo et al. 2003; Duchamp et al. 2006) and weather surveillance radars (Kelly et al., 2012) promise to revolutionize the capacity to accurately assess bat activity patterns (phenology) in a species-specific manner over relatively broad spatial extents using comparable approaches (e.g., Horn and Kunz, 2008; Kunz et al. 2008).

Bats occupy a variety of ecological niches, consuming a broad array of resources (e.g., fruits, nectar, invertebrates, terrestrial vertebrates, fish, and blood) and affecting the structure of food webs within terrestrial and aquatic communities. As a result, bats can directly or indirectly reflect the abundance and distribution of many other species (e.g., plants and insects), as well as the flow of energy or the cycling of nutrients within and among ecosystems. In addition, bats perform a suite of critical ecosystem functions (e.g., pollination, seed dispersal, insect population regulation) that are directly linked to services that enhance human welfare (e.g., commercial fruit production, insect pest control). Equally important, bats perform important roles in facilitating succession or enhancing recovery from natural and human-induced disturbances (contributing indirectly to carbon sequestration). Finally, bats respond to a variety of disturbances such as those associated with habitat conversion, habitat loss and fragmentation, hunting, urbanization, and pollution, and do so at multiple spatial scales (Jones et al., 2009).

Because of their sensitivity at multiple spatial scales to a broad range of disturbances and stressors, bats may constitute an effective biodiversity indicator whose monitoring is both accurate and cost-effective. Indeed, the responses of bats to global change drivers recommends them for consideration in the implementation of local, regional, or global networks of biological indicators (Jones et al., 2009).

CLIMATE CHANGE.--Bat mortality is associated with climatic extremes such as temperature maxima or minima and precipitation maxima or minima (e.g., Bourne and Hamilton-Smith, 2007; Welbergen et al. 2008; Jones et al., 2009). Because many bats in temperate environs hibernate, they are particularly sensitive to increasing temperatures associated with global warming (Humphries et al., 2002). Similarly, roosts of some bat species are susceptible to sea level rise (McWilliam, 1982), a particularly severe problem for island populations. Moreover, bat populations and communities are affected by disturbance regimes associated with cyclonic storms or droughts (Willig and McGinley, 1999) whose frequency, intensity, and scale are projected to be modified as a result of global change. Finally, bat mortality is affected by renewable energy technologies such as wind turbines (Johnson et al., 2003; Kunz et al. 2008; Voigt et al. 2012), which likely will become more abundant and widespread as humans attempt to curb carbon emissions associated with dependence on fossil fuels.

LAND USE CHANGE.--Bat populations, functional groups, and communities respond to the conversion of forests to other land uses (Fenton et al. 2009). For example, the abundances of 8 species of frugivorous bat differed among closed canopy forest, early successional forest, and cultivated fields in Amazonian Peru (Willig et al. 2007). In addition, temporal activity patterns of 5 species of frugivore differed between agricultural fields and intact or successional forest, but no differences occurred between successional and closed canopy forest. Bats also respond to variation in landscape structure (number, sizes, and juxtaposition of forest patches) associated with human activities and do so in guild-specific and scale-dependent fashion (e.g., Schulze et al. 2000; Gorresen and Willig, 2004; Gorresen et al., 2005; Klingbeil and Willig, 2009; Klingbeil and Willig, 2010). There is similarly strong evidence that bats respond to urbanization (e.g., Kunz and Reynolds, 2003), agricultural intensification (e.g., Stebbings, 1988; Wickramasinghe et al., 2003), and pollution (e.g., Jeffries, 1972; Clark et al. 1978; Racey and Swift, 1986).

Biodiversity Monitoring Network

In a broad review of the current understanding of bat biology, Jones et al. (2009) convincingly argued that it is time to "capture the night" (carpe noctem) and utilize the full potential of bats as global sentinels for change. I reiterate that suggestion and provide a number of criteria for consideration in initiating, implementing, and maintaining a global network for bats as biological indicators.

Network design should be sufficiently flexible so as to capture global and continental responses to drivers of change, as well as to capture regional and local responses to drivers of change (i.e., drivers of change at the local scale can be quite different from drivers of change at regional or global scales). The balance of interest between these scales should be determined by the overarching question or questions that motivate the network.

The global network can be distributed and federated in nature (i.e., a network of networks). This will likely arise because of funding realities associated with the political nature of national priorities for science. Nonetheless, a set of minimum characteristics associated with the overarching goal of capturing change at a global scale should be considered for inclusion.

To ensure a high likelihood of being able to answer specific questions about biodiversity and global change scenarios, careful consideration of sampling design and its efficacy in light of estimates of variability should precede selection of sampling sites or implementation of sampling protocols (Andelman and Willig 2004).

Multidisciplinary participation in network design by scientists with expertise in conservation, ecology, population biology, biogeography, systematics, land use change, climate change, and statistics or modeling would enhance the likelihood of success and the long-term value of the network.

Recent success in creating an "open-source network" should be considered in the absence of substantial international, national or private funding (see Adler et al. [2011] and Stokstad [2011] for a possible mechanism).

Partnerships with and expansion of citizen science programs that focus on bats (e.g., iBat) as well as other taxa can provide valuable data for informing conservation action and biodiversity science (Walters et al. 2012). The full potential of these activities may be enhanced considerably by embracing modern communication (e.g., mobile phones and global positioning devices) and cyberinfrastructure advances (e.g., cycle scavenging, crowd sourcing, cognitive surplus, and human computation). The education and outreach potential of these activities are considerable, and provide a mechanism for affecting the issues that the public considers when balancing natural resource issues with other concerns.

A combination of approaches for sampling bats should be developed, including conventional approaches (use of mist nets or harp nets), acoustic monitoring, and radar surveillance.

Information management is critical to the long-term success of any network, especially if integration and synthesis is a requirement. Care should be taken to provide adequate metadata for collected data, especially as it relates to effort (spatial and temporal domains) and systematics.

Monitoring should be conducted in collaboration with the IUCN Bat Specialist Group. This would guarantee that current scientifically validated conservation status is included in monitoring activities and that collected data about bats as biological indicators can be used to clarify the conservation status of species listed as "Data Deficient", thereby improving the "Red List" process (see Lacher et al., 2012) .

Generally, results from network activities should be freely available to the scientific and professional community.

In conclusion, framing a vision for the network will require a careful consideration of data quantity and quality, tradeoffs associated with the scales at which questions will be answered, models for quantifying biotic change and enhancing predictive understanding, and the quantitative tools that will be used to inform conservation action and policy. Given the magnitude of the biodiversity crises, and the nature of threats that promise to exacerbate it in the near future, the time is literally now or never for mobilizing the scientific community to adopt a multi-scale global network based on bats as biological indicators.

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Figure 1.--*Global maps of the anthropogenic biomes of the world for 1700, 1800, 1900, and 2000. The sequence illustrates 300 years of increasing intensity and pervasiveness of human modified landscapes (modified from Ellis et al., 2010). Numbers indicate general categories: Dense settlements--urban settlements (11) and mixed settlements (12); Villages--rice villages (21); irrigated villages (22); rain-fed villages (23); and pastoral villages (24); Croplands--residential irrigated croplands (31), residential rain-fed croplands (32), populated croplands (33), and remote croplands (34); Rangelands--residential rangelands (41), populated rangelands (42), and remote rangelands (43); Seminatural areas--residential woodlands (51), populated woodlands (52), remote woodlands (53), and inhabited treeless and barren lands (54); and Wildlands--wild woodlands (61), and wild treeless and barren lands (62).*