



A theoretical approach to using human footprint data to assess landscape level conservation efforts

Aaron M. Haines¹, Matthias Leu², Leona K. Svancara³, J. Michael Scott⁴, & Kerry P. Reese⁵

¹ Center for Research on Invasive Species and Small Populations, University of Idaho, CNR Room 103A, Moscow, ID 83844-1141

² United States Geological Survey, Forest and Rangeland Science Center, Boise, ID 83706

³ Idaho Conservation Data Center, Idaho Department of Fish and Game, and the University of Idaho, Moscow, ID 83844-4061

⁴ United States Geological Survey, Idaho Cooperative Fish & Wildlife Research Unit, University of Idaho, CNR Room 103, Moscow, ID 83844-1141

⁵ Department of Fish & Wildlife Resources at the University of Idaho, CNR Room 104, Moscow, ID 83844-1136

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Correspondence

Aaron M. Haines, Upper Iowa University,
Division of Science and Mathematics, P.O. Box
1857, 605 Washington St., Fayette, Iowa 52142.
Tel: 563-425-5222; fax: 563-425-5287.
E-mail: hainesa@uiu.edu

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Abstract

Conservation organizations are increasingly being held accountable for identifying and documenting measures of conservation success. We propose the use of human land-use spatial data to aid in the assessment of conservation efforts by monitoring qualitative change in the human footprint (i.e., spatial land-use measures of negative anthropogenic activity) within a hypothesis-driven framework to assess the effects of conservation efforts (i.e., positive anthropogenic activity). If human footprint data show that implemented conservation strategies mitigated or reduced negative anthropogenic influences, then a potential conservation approach is working. In contrast, if the implementation of conservation strategies did not mitigate or reduce the human footprint, then new conservation approaches may need to be developed or old ones refined. Human footprint data may offer great potential for assessing conservation efforts when used as part of a larger conservation monitoring strategy.

Introduction

Although conservation organizations are increasingly being held accountable for identifying and documenting measures of conservation “success” (Margoluis & Salafsky 1998), they have done little to identify goals for conservation success (Dalton 2006). In addition, when it comes to evaluating the success of interventions, the fields of ecosystem protection and biodiversity conservation lag behind most other policy fields such as poverty reduction, criminal rehabilitation, and disease control (Ferraro & Pattanayak 2006). For example, the Millennium Ecosystem Assessment report of 2005 stated that “few well-designed empirical analysis assess even the most common biodiversity conservation measures” (Ferraro & Pattanayak 2006). Thus, one can argue that the effectiveness of current conservation actions is limited, especially at broad spatial scales. However, recent management frameworks have been developed to eval-

uate conservation projects and measure conservation efforts (Salafsky *et al.* 2002; Parrish *et al.* 2003; Ruiz-Jaen & Aide 2005; Davis *et al.* 2006; The Nature Conservancy 2006; Murdoch *et al.* 2007). These efforts may include maintaining and/or restoring ecological integrity, ecosystem function, and plant and animal communities, and minimizing threats to natural areas and sensitive species.

Salafsky *et al.* (2002) provided a framework for conservation practice by identifying conservation targets, human threats to these targets, conservation strategies to address human threats, and monitoring strategy implementation. Parrish *et al.* (2003) proposed the use of “ecological scorecards” to identify focal conservation targets, identify key ecological attributes of those targets, define when targets are conserved, and assess their status. Parrish *et al.* (2003) defined key ecological attributes as not only a conservation target’s biological composition, but also the biotic interactions and processes,

environmental regimes and constraints, and attributes of landscape structure and architecture that sustain a target's composition and its natural dynamics. Ruiz-Jaen and Aide (2005) suggested the evaluation of at least two of three ecosystem attributes (i.e., diversity, vegetation structure, and ecological processes) in comparison to reference sites to measure restoration success. For the last 10 years, The Nature Conservancy (2006) has used the "conservation by design" approach to set goals, develop strategies, take actions, and measure results to evaluate effectiveness of their conservation strategies. Both Davis *et al.* (2006) and Murdoch *et al.* (2007) developed cost-effective analysis models, which identify the cost of conservation actions in comparison to conservation gains, to be used as decision support tools for conservation planning efforts. We suggest that these management frameworks and models incorporate spatial monitoring of anthropogenic land-use activities which may impact ecological attributes of conservation targets within a hypothesis-driven framework (i.e., do we accept or reject the hypothesis that on-the-ground conservation efforts mitigate anthropogenic activity) to assess the effects of conservation efforts and validate model predictions.

Human land-use (primarily habitat degradation/loss and introduction of exotic species) has been identified as one of the greatest threats to biodiversity (Wilcove *et al.* 1998). Such land-use has the potential to influence plant/wildlife communities and ecosystems negatively by altering the chemical and physical environment (e.g., fragmentation) (Thompson & Jones 1999; Trombulak & Frissell 2000), establishing vectors for ecological traps (e.g., exotic species invasions) (Rich *et al.* 1994; Trombulak & Frissell 2000), causing direct mortality (e.g., vehicle-collisions) (Thompson & Jones 1999; Trombulak & Frissell 2000), and altering animal behavior (e.g., reduced dispersal) (Rich *et al.* 1994; Trombulak & Frissell 2000). We refer to spatial data or spatial indicators of anthropogenic activities that have the potential to impact conservation targets negatively as "human footprint" data (Sanderson *et al.* 2002; Leu *et al.* 2008).

Conversely, human activities also have the potential to impact conservation targets positively via conservation strategies. These strategies may include habitat restoration/management (Morrison 2002; Bunting *et al.* 2003; Armitage *et al.* 2007), control of exotic species that impact or compete with native flora and fauna (Harding *et al.* 2001; Nordstrom & Korpimaki 2004), prescribed burns as a management tool for restoration of various grassland and forest habitats (Allen *et al.* 2006; Monroe & Converse 2006), establishment of conservation agreements (Gray & Teels 2006), and strategies used in green urbanism (Beatley 2000).

The spatial monitoring of human footprint data has the potential to advance the assessment of conservation efforts that implement strategies such as those listed above (e.g., conservation agreements, green urbanism strategies, etc.). By monitoring the changes in human footprint data over time, one may have the potential to assess whether conservation efforts that implement such strategies are indeed mitigating or reducing the human footprint across a defined landscape or ecosystem at a specified spatial and temporal scale.

Identifying the human footprint

The human footprint is a collection of spatial data which rely on a Geographic Information System (GIS) approach to map anthropogenic features and to model impact areas of those features (i.e., the area influenced by an anthropogenic feature beyond its physical area) (Sanderson *et al.* 2002; Leu *et al.* 2008). The investigation of anthropogenic features or disturbance patterns may change depending on the scale of analysis and extent of inference. Therefore, the identification and importance of specific human footprint data will depend on the questions being asked and the scale of the analysis.

For example, at a global scale, Sanderson *et al.* (2002) developed human footprint data based on anthropogenic features influential at this scale such as population density, land transformation, human access, electrical power infrastructure, and global terrestrial biomes. At a more regional scale, Leu *et al.* (2008) delineated the human footprint for the western United States based on the area of ecological influence by anthropogenic features beyond their physical footprint (i.e., the actual area covered by anthropogenic features) for anthropogenic point features (e.g., campgrounds, landfills, and energy extraction wells), line features (e.g., major roads, secondary roads, railroads, power lines, and irrigation canals), and polygon features (e.g., agricultural land and urban areas). However, the identification of human footprint data could also be created for other regions around the globe. For example, global spatial datasets of recent satellite imagery and land cover classifications can be found on GIS data websites such as Earth Explorer (<http://edcscns17.cr.usgs.gov/EarthExplorer/>), the Center for International Earth Science Information Network (CIESIN) (www.ciesin.org), and the United Nations Environment Programme's Global Resource Information Database (<http://na.unep.net/datasets/datalist.php>).

For a more local human footprint dataset, we downloaded land-use cover data, and remotely sensed data created from aerial photos and Landsat satellite imagery from the Enhanced Historical Land-Use and

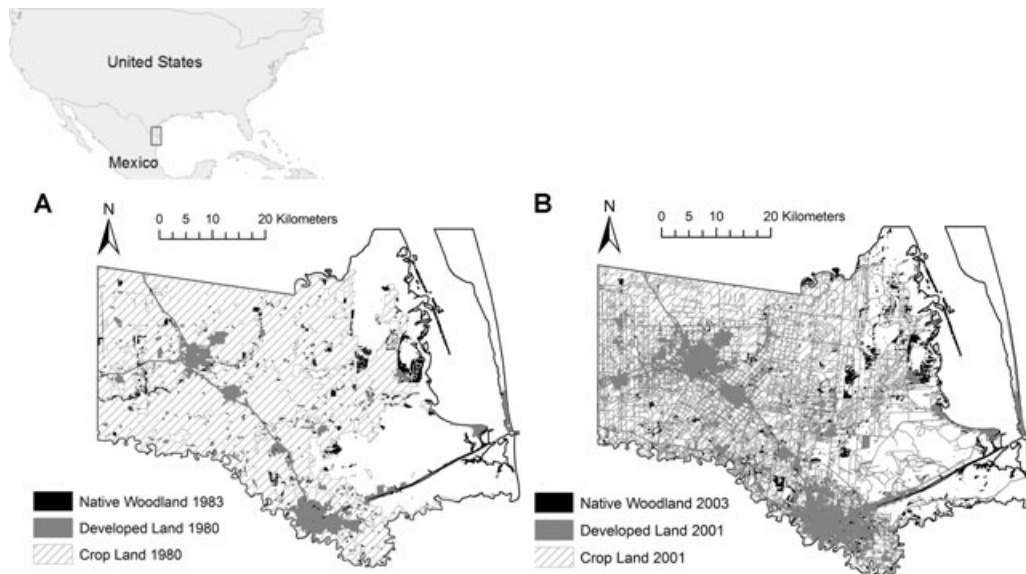


Figure 1 Change in native woodland cover and the human footprint (i.e., developed land and crop land) from a) the early 1980s to b) the early 2000s in Cameron County, Texas, United States.

Land-Cover Data Sets of the U.S. Geological Survey (accessed 22 January 2008, <http://water.usgs.gov/GIS/dsdl/ds240/index.html>) and the National Land-use Cover Database 2001 (accessed January 22, 2008, <http://www.mrlc.gov/mrlc2k.nlcd.asp>) to identify changes in the human footprint over time within the borderlands of the United States and Mexico (Figure 1).

To investigate temporal changes in the human footprint, human footprint data need to be developed during two or more separate time periods (Figure 1). This technique of using multitemporal data to discriminate areas of change is known as “change detection” (Jensen 2005). Numerous methods of change detection, such as using aerial photography to detect changes in road densities and extent (Hawbaker *et al.* 2006) or Landsat imagery to estimate land-cover change across large scales (Loveland *et al.* 2002), are available and their applicability and efficacy depend on project objectives, spatial and temporal scale, type of data (e.g., geographic datasets, remotely sensed data), and environmental characteristics (Coppin *et al.* 2004; Lu *et al.* 2004). These factors are defined by the nature of the anthropogenic threat itself.

The types of human footprint data that can be monitored spatially may include changes in: (1) land-use patterns such as changes in impervious surfaces (i.e., developed lands), (2) agricultural lands, (3) densities of roads, energy extraction wells, landfills, water wells, and (4) other potentially negative anthropogenic impacts (Leu *et al.* 2008). Thus, human footprint data could be used to assess conservation efforts that are trying to reduce the

growth of developed lands and other human structures within key conservation target areas. By correctly observing human footprint data using a hypothesis-driven approach, one could then evaluate whether conservation efforts are mitigating or reducing human footprint growth in areas with conservation targets by monitoring the change in these human footprint data over time.

The human footprint concept as an applied tool

When developing a spatial monitoring strategy for a conservation target, it is important to identify clearly the scales and the changes that will be monitored on the landscape which impact the identified conservation target (Morrison 2002). Therefore, one has to be aware of how species targeted for conservation action will respond to various types and degrees of anthropogenic activity (e.g., difference in activity and behavior, increased or decreased fertility or survival, changes in physiological growth rates, etc.). Knowledge of species and/or ecosystem responses to various anthropogenic activities is the basis for using human footprint data to monitor the effectiveness of implementing conservation strategies.

The monitoring of human footprint data can potentially be used to identify if the implementation of conservation strategies reduces or mitigates anthropogenic activities. If changes in the human footprint indicate that implemented conservation strategies (e.g., invasive

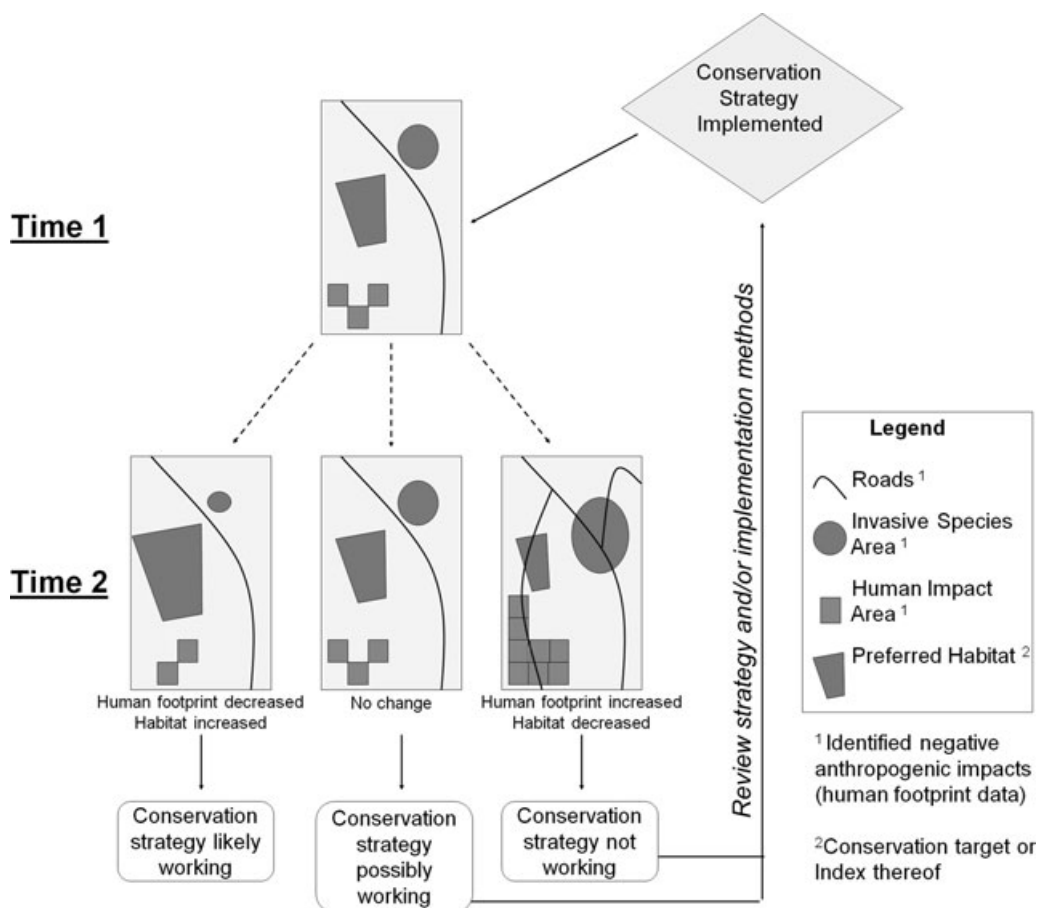


Figure 2 Monitoring human footprint spatial data to assess conservation efforts.

species control, habitat restoration, etc.) have mitigated or reduced the human footprint and expanded necessary habitat (i.e., conservation target or index thereof) over a defined landscape (i.e., impact area of a conservation target) then a potentially effective implementation of a conservation strategy has been found. However, if the implementation of conservation strategies does not mitigate the human footprint and habitat continues to decline over time, then barriers to implementing conservation strategies may need to be identified and/or new strategies developed (Figure 2).

For example, within the borderlands of the United States and Mexico, the ocelot (*Leopardus pardalis*) is listed as an endangered species under the United States Endangered Species Act with only 80–120 individuals remaining (Haines *et al.* 2006). Ocelot conservation depends on the presence of native woodland cover and the mitigation of ocelot vehicle collisions (Haines *et al.* 2006). Thus, the effectiveness of ocelot conservation may be considered effective if the amount of remotely sensed native woodland cover increases over time while simultaneously the

land-use surrounding native woodland cover is not converted to roads or developed land (Tremblay *et al.* 2005; Haines *et al.* 2006). During the 20-year change within the borderlands of the United States and Mexico, the area of native woodland cover has stayed relatively constant but the amount of developed land and roads has increased (Figure 1), thus suggesting that ocelot conservation efforts have not been effective.

In addition to our example given above, Oliveira *et al.* (2007) monitored various rates of deforestation in the Peruvian Amazon using Landsat satellite images monitored over a 15-year period. They found that forests within natural protected areas, indigenous territories, and recent forest concession areas contained lower rates of forest disturbance and deforestation in comparison to surrounding areas, thus suggesting that land-use policy can serve to protect the Peruvian Amazon.

However, monitoring of landscape change is a slow process and one cannot determine if changes on the ground may be the result of conservation efforts, or lack thereof, if only one site is being monitored. Therefore,

a scientific evaluation is needed on the basis of reliable empirical data to assess what would have happened if there had been no conservation effort made (Frondel & Schmidt 2005; Ferraro & Pattanayak 2006).

We propose that monitoring of the human footprint be conducted as a retrospective study to evaluate the influence of conservation efforts (Morrison 2002). Evaluation of conservation efforts can be conducted by implementing conservation strategies on a defined landscape (i.e., treatment landscape) and monitoring change in the human footprint over time, while concurrently comparing changes of the human footprint across a similar landscape in which no conservation strategies have been implemented (i.e., control landscape) (Ruiz-Jaen & Aide 2005). This hypothesis-driven approach can be conducted using a before–after/control impact (BACI) experimental design (Green 1979; Stewart-Oaten *et al.* 1986). A BACI design would involve an analysis of human footprint data on separate sites where potential negative impacts had occurred. Within these sites, conservation actions would be applied to treatment sites while no conservation action would be implemented to control sites (i.e., left as it is) and then examining site response to conservation actions over time. The interaction between implemented conservation action and time would indicate if conservation efforts were successful in mitigating human footprints. In

addition, to using a BACI experimental design we recommend using multiple control and treatment sites that are relatively similar and chosen at random if possible. This will help reduce the impacts of confounding effects on experiment results and increase the interpretability of data (Conquest 2000).

By implementing a BACI experimental design, we can hypothesize that human footprints can be reduced in response to implemented conservation strategies. If treatment landscapes exhibit a smaller human footprint and expanded habitat in comparison to control landscapes, then implementation of conservation strategies have evidence to suggest effectiveness, thus supporting our hypothesis. However, if the treatment landscapes exhibit a similar or larger human footprint and similar or lower habitat in comparison to the control landscapes, then implementation of conservation strategies may need to be reevaluated and/or new strategies developed, and our hypothesis is rejected (Figure 3).

The human footprint and public outreach and communication

Policy-makers, land managers, and the majority of the voting public in democratic societies rarely read scientific journals (Dennison *et al.* 2007), but these individuals

CURRENT CONDITION (TIME 1)		CONTROL (TIME 2: NO STRATEGY)			
		Footprint: Decreased Habitat: Increased	Footprint: No change Habitat: No change	Footprint: No change Habitat: No change	Footprint: Increased Habitat: Decreased
TREATMENT (TIME 2: STRATEGY)	Footprint: Decreased Habitat: Increased	Influence of conservation strategy unknown. Additional monitoring and evaluation needed.	Conservation strategy may be working. Review of strategy and/or implementation methods needed.	Conservation strategy working. Continue monitoring.	
	Footprint: No change Habitat: No change	Conservation strategy not working. Review of strategy and/or implementation methods needed.	Influence of conservation strategy unknown. Additional monitoring and evaluation needed.	Conservation strategy may be working. Review of strategy and/or implementation methods needed.	
	Footprint: Increased Habitat: Decreased	Conservation strategy not working. Review of strategy and/or implementation methods needed.	Conservation strategy not working. Review of strategy and/or implementation methods needed.	Influence of conservation strategy unknown. Additional monitoring and evaluation needed.	

Figure 3 A decision matrix using change in human footprint spatial data over time to evaluate the effectiveness of conservation efforts by comparing an area where a conservation strategy had been implemented (treatment) to an area where no conservation strategy had been implemented (control).

influence land-use planning decisions that impact our natural resources. Therefore, conservation biologists require better communication tools to simplify scientific data to increase public understanding of research findings. Visual representation of conservation efforts through remote sensing data, aerial photos, and maps using GIS can increase public understanding of complex data and facilitate communication among diverse stakeholders by providing a common language to achieve conservation objectives (Dennison *et al.* 2007).

The human footprint is a spatially explicit approach to conservation planning that may serve as an effective visual medium to public audiences and stakeholders worldwide by simplifying the presentation of complex information. By presenting clear illustrations of spatial data changing over time, audiences can visualize ecological impacts of anthropogenic activity as it specifically relates to natural areas and wild species. In addition, audiences can easily evaluate which conservation strategies were effective at mitigating anthropogenic impacts. Increased public and stakeholder understanding of the changing landscape and the conservation process may generate more support and implementation of effective conservation efforts.

Precautions and recommendations for human footprint data

Sanderson *et al.* (2002) stated that human footprint data were too inexact to provide much insight for site-based conservation and instead recommended “on the ground” efforts to monitor the impacts of conservation action. However, since the publication of this groundbreaking article, spatial data (e.g., distribution of anthropogenic features across the western United States see SAGEMAP [<http://sagemap.wr.usgs.gov/>]) have been updated and improved, and other efforts to define the human footprint at more regional scales, rather than global, have been conducted (Leu *et al.* 2008).

With any monitoring approach, one must be aware of the underlying assumptions and limitations of the methods (Morrison 2002). For example, spatial data may reflect imperfect representations of the “on-the-ground” environment because of inaccuracies or mistakes in remotely sensed data, especially at broad spatial scales (Sanderson *et al.* 2002; Grainger 2008). Therefore, monitoring of landscapes using human footprint data should occur at scales appropriate to the spatial data being used. In addition, care must be taken in identifying real change versus nonchange variation (i.e., due to temporal, spatial, spectral, or radiometric differences) (Jensen 2005). For instance, identified areas of change in anthropogenic

features may be due to more reliable mapping techniques rather than true changes. Therefore, it is important to assess the accuracy of mapped or modeled anthropogenic features via comparisons with either aerial photography, updated spatial data from land management agencies, or independent field surveys (Koh & Wilcove 2008).

The greatest limitation of using human footprint data to assess conservation efforts is that spatial patterns of human influence are constrained by complex interactions between humans and the environment (Sanderson *et al.* 2002), thus spatial data rarely produce a complete picture of what negative impacts are occurring because human footprint data are not well-suited to track anthropogenic impacts that lack a spatial signature (Leu *et al.* 2008). For example, the spread of some chemical pollutants, invasive species, diseases, and impacts of poaching cannot be monitored spatially, thus other monitoring strategies of biological indicators (i.e., more direct indexes of the health of conservation targets) are also needed to assess conservation efforts. However, spatial data of human footprints can also be used indirectly to monitor sources of pollutants (e.g., agricultural fields), vectors of disease, and spread of invasive species (e.g., development bringing in domesticated animals and plants). Therefore, spatial data of human footprints can be used in unison with other biological indicators to assess the effectiveness of conservation efforts. In addition, the implementation of conservation strategies to mitigate or reduce human footprints should not be a trial-and-error approach, but a learning process that improves our understanding of why certain conservation strategies worked or did not work and under what conditions (Salafsky *et al.* 2002).

In addition to issues dealing with experimental design and methodology, the analyses of results also need to be evaluated with caution. When land-use restrictions are evaluated as conservation actions one has to be aware if “leakage” has taken place—where human impacts might be displaced from a restricted-use area to an unrestricted area (Ewers & Rodrigues 2008). The issue of linkage may be quantified by including buffer areas around control and treatment sites to also be evaluated within a BACI approach, as suggested by Ewers and Rodrigues (2008). If buffer areas surrounding treatment sites, which have land-use restrictions implemented as conservation actions, show an increase in anthropogenic land-use activities while the treatment site shows a decrease then leakage may be occurring. This may further suggest that your conservation action is effective at reducing negative anthropogenic activity, however, if the overall goal is to mitigate negative impacts across an entire landscape than other conservation actions may be more effective (e.g., incentive programs, government subsidies, public outreach, etc.).

Unfortunately, we are unaware of any organization that has fully implemented and completed the monitoring of human footprint data over time to assess conservation efforts using a hypothesis driven approach. However, both public and private land-use planners and conservation organizations may find it useful to apply human footprint spatial data via a retrospective study using a before–after/control impact (BACI) experimental design with multiple control and treatment sites to assess and validate the effectiveness of conservation efforts for land-use planning or open space use systems (Ahern 1991, Thompson 2002).

Lastly, we recommend that the monitoring of human footprint data *not* be relied upon entirely. Spatial human footprint data should be used in unison with other assessment techniques (e.g., interviews with individuals on the ground, direct indexes of the health of conservation targets, etc.) as part of a larger conservation planning framework like those used or recommended by Salafsky *et al.* (2002), Parrish *et al.* (2003), Ruiz-Jaen and Aide (2005), The Nature Conservancy (2006), Davis *et al.* (2006), and Murdoch *et al.* (2007) to assess conservation efforts.

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