Popul Environ (2014) 36:73–84
DOI 10.1007/s11111-014-0203-6

ORIGINAL PAPER

Long-term dynamics of household size and their environmental implications

Mason Bradbury · M. Nils Peterson · Jianguo Liu

Published online: 6 February 2014

Abstract Little is known about the environmental implications of long-term historical trends in household size. This paper presents the first historical assessment of global shifts in average household size based on a variety of datasets covering the period 1600–2000. Findings reveal that developed nations reached a threshold in 1893 when average household size began to drop rapidly from approximately 5.0 to 2.5. A similar threshold was reached in developing nations in 1987. With the notable exceptions of Ireland, and England and Wales in the early 1800s, and India and the Seychelles in the late 1900s, the number of households grew faster than population size in every country and every time period. These findings suggest accommodating housing may continue to pose one of the greatest environmental challenges of the twenty-first century because the impacts of increased housing present a threat to sustainability even when population growth slows. Future research addressing environmental impacts of declining household size could use an adapted IPAT model, $I = \text{PHoG}$: where environmental impact (I) = population × personal goods (P) + households × household goods (HoG).

Electronic supplementary material The online version of this article (doi:10.1007/s11111-014-0203-6) contains supplementary material, which is available to authorized users.

M. Bradbury · J. Liu
Department of Fisheries and Wildlife, Center for Systems Integration and Sustainability, Michigan State University, East Lansing, MI 48823, USA
e-mail: liuji@msu.edu

Present Address:
M. Bradbury
Department of Society and Conservation, University of Montana, Missoula, MT 59812, USA

M. N. Peterson (✉)
Fisheries, Wildlife, and Conservation Biology Program, North Carolina State University, Raleigh, NC, USA
e-mail: nils_peterson@ncsu.edu

Keywords Conservation biology · Environmental impact · Household size · IPHoG · Population · Sustainable development

Introduction

The impacts of human population size on the environment and natural resource consumption have concerned scientists since at least 1798 when Malthus published *An Essay on the Principle of Population* (Malthus [1798] 1970; Wolman 2001). Ehrlich and Holdren helped frame concerns about the influence of human population on the environment with their famous model, $I = \text{PAT}$: where impact (I) = population (P) $\times$ affluence (A) $\times$ technology (T) (Ehrlich and Holdren 1971). Since the early 1970s, many researchers have found correlations between population size and impacts on resources including water, air, and plant and wildlife species (de Sherbinin 1998; Thompson and Jones 1999). Population growth, however, is slowing and even reversing in some places. Most of Europe, North America, and many developing nations including Brazil, China, Chile, and Costa Rica had birthrates below replacement levels in 2010 (at least 45 nations faced absolute declines in population size in 2010 (World Population Prospects: the 2008 Revision 2008)).

Progress made in curbing population growth, however, has not translated into reducing human consumption of natural resources and impact on the environment. This can be explained in part by social forces leading to declining population growth rates (e.g., increasing affluence and increasing educational levels among women) contributing to higher numbers of households per capita (Burch and Matthews 1987; Keilman 2003; Liu et al. 2003). Household proliferation is also due to aging, increasing divorce rates, and decreasing incidence of multigenerational households, which may be partly attributable to changing preferences for privacy (Klinenberg 2012; Yu and Liu 2007; Beresford and Rivlin 1966). Indeed, the number of households may grow globally despite population numbers stabilizing (Peterson et al. 2013). According to convergence theory, household size decreases (often from >5 to <3) as a society undergoes urbanization and industrialization (Goode 1963). This trend largely occurred in developed nations during the latter part of the 1800s (Bongaarts 2001). If convergence theory applies to today's developing nations, billions of households could be formed despite declines in population growth.

Since households are the end consumers of most natural resources and ecosystem services, they pose a critical challenge for conservation (Bearer et al. 2008; Chen et al. 2010; He et al. 2008; Liu 2013). A growing body of research suggests that households should be included with population as a factor in the I = PAT model. The number of households is often equal to, or better than, population at predicting CO_2 emissions (MacKellar et al. 1995), fuelwood consumption (Clinecole et al. 1990), per capita automobile use (Liddle 2004), and species endangerment (Lepczyk et al. 2008; Peterson et al. 2007). For example, population growth accounted for only one-fourth of increased energy consumption in the 1970s and 1980s, whereas the remaining 3/4 was related to per capita increases driven largely by households (MacKellar et al. 1995). Looking specifically at India, households can be seen as key consumer units and, in fact, use over 70 % of total primary energy (Pachauri 2007).

Given the importance of households in resource consumption (An et al. 2001; Pachauri 2007), focusing on households may be key to reducing human environmental impacts (Dietz et al. 2009; Peterson et al. 2013). As such, the relative lack of research on the environmental implications of historical household dynamics represents a conspicuous gap in our understanding of interactions between human population and the environment. Household demography has lagged behind population demography for decades (Bongaarts 2001). This disparity reflects difficulty in defining households, the high variability of household composition (relative to individuals), less reliable household data, and less temporal precision and breadth for household data as compared to population data. Even in developed nations with long histories of demographic data collection, household definitions may change significantly over time (Ruggles and Brower 2003). These challenges mean most household dynamics research has been limited to developed countries, recent history, and regional case studies (Burch 1967; Frankel and Webb 2001; Laslett 1974; Liao 2001). A notable exception is Bongaarts' (2001) evaluation of temporal trends among nine less developed countries mostly between 1950 and the early 1990s. Over this period, household size decreased in five of the nine countries, but was relatively stable or even increased in four cases.

In this research brief, we extend previous analyses by evaluating historical changes (from 1600 to 2000) in household size among 213 extant and non-extant nations, territories, colonies, and protectorates. The unprecedented temporal and geographic breadth of data provides unique insights into understanding demographic transition in household size. We also compare the growth rates of both population size and number of households during various time periods. Furthermore, we discuss the environmental implications of household dynamics (i.e., changes in numbers of households and household size).

Methods

Data collection

Much of the data for household dynamics since 1985 were collected through previous research by members of the research team (Liu et al. 2003). Historical data were collected from government documents (censuses, statistical abstracts, yearbooks, and books authored by demographers), and the UN's Demographic Yearbook series (see Electronic Supplementary Material). Although global data were used, many nations have not monitored changes in household size historically, and definitions of a household have varied over time and across countries (see Electronic Supplementary Material for definitions). Accordingly, our results should be seen as exploratory, and a means to highlight future research needs.

The distinction between developed and developing countries was based on the classification used in 2013 by the United Nations Statistics Division in which Japan, Australia, New Zealand, Canada, the United States, and Europe are considered developed, and the rest of the world is considered developing (http://unstats.un.org/unsd/methods/m49/m49regin.htm#developed). Following this convention, we classified any territories or protectorates located on the North American or European continents or in the North Atlantic as developed. For a list of countries, household definitions, and year specific data sources for each country, please see the Electronic Supplementary Material.

Data analysis

The diverse datasets created some standardization challenges. We included all data from the oldest records to the year 2000 in the regression models predicting household size as a function of year. Graphs include extant countries with five data points beginning 1960 or before and ending between 1990 and 2000. This approach yielded 213 nations or protectorates and 825 data points for the regression models, 30 nations for Figs. 2 and 3, and 402 household size data points for Fig. 2. Total household and population numbers were used to generate annual percentage changes as shown in Fig. 3. Thresholds where household size and ultimately the growth rate of house numbers change rapidly are defining attributes of convergence theory (Goode 1963) and demographic transition theory in general. The theories predict one or more thresholds with segments of time before and after that have measurably different household size growth rates. We determined whether such thresholds existed and when they occurred using a breakpoint in linear models of household size for both developing and developed nations using the R package "segmented" (Muggeo 2008). The segmented package estimates linear models with one or more breakpoints between segments and provides slope estimates for each segment. Bootstrap restarting in the segmented regression models was used to make the algorithm relatively insensitive to starting values (Wood 2001). We used the Davies' test to determine whether a significant change in slope occurred at the breakpoint (Davies 1987; Muggeo 2008).

Results

Household size has been declining in developed nations for several hundred years, but the trend accelerated at the start of the twentieth century (Fig. 1). Breakpoint regression results suggest a threshold in household size for developed nations in 1893. The change in slope between years prior to 1893 (−0.002287) and years after 1893 (−0.019804) was statistically significant ($p < 2.2e{-}16$). The segmented model for developed countries had strong predictive capacity ($R^2 = 0.71$; Fig. 1).

Convergence toward nuclear households is occurring in developing nations as well, as a breakpoint was identified in 1987 (Fig. 1). The change in slope between years prior to 1987 (−0.01164) and years after 1987 (−0.07822) was statistically significant ($p < 1.3e{-}6$). These slopes suggest that in the 1980s, declines in average

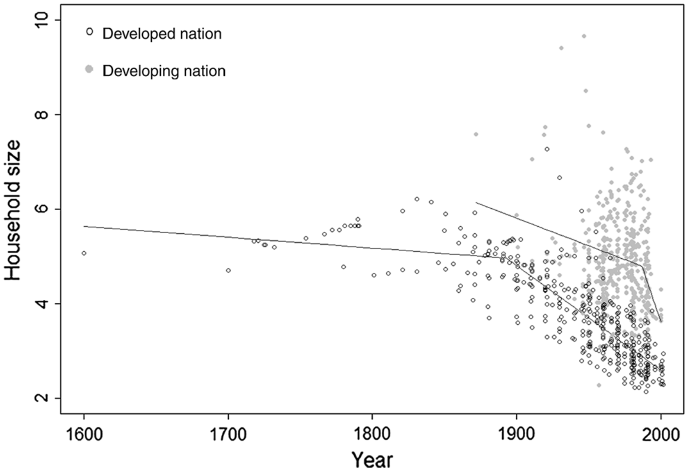

Fig. 1 Breakpoint regression model of household size and year in developed and developing nations. Each point represents average household size for one nation during the census for the corresponding year

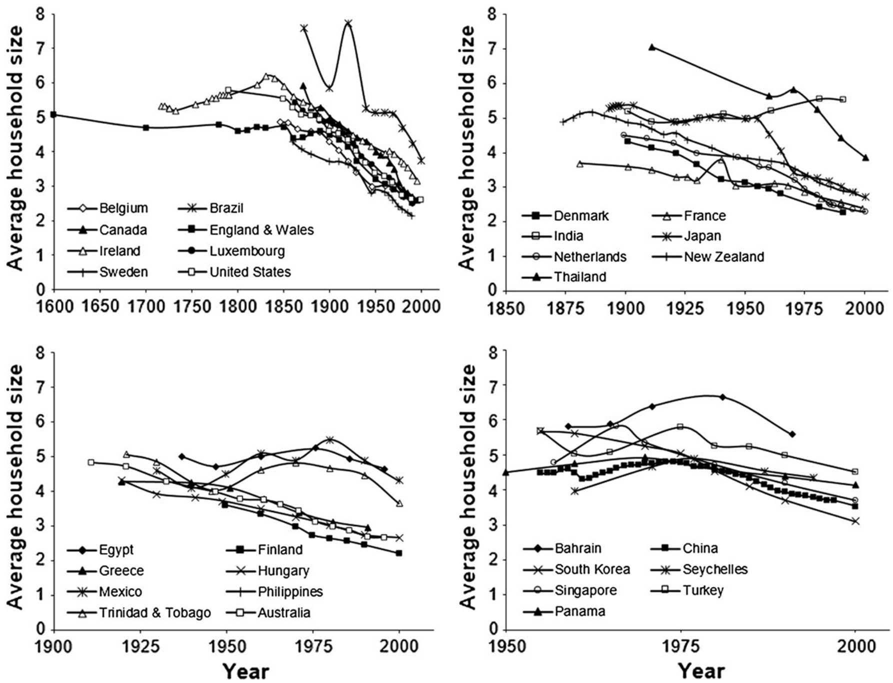

Fig. 2 Plots of household size change between 1600 and 2000

household size among developing countries surpassed the highest rates ever observed for developed nations. For developing countries, however, the segmented model had weak predictive power ($R^2 = 0.08$; Fig. 1).

Of the 30 nations featured in Fig. 2, all except the Seychelles and India experienced a decrease in average household size over time, but some, such as Brazil, Trinidad and Tobago, Mexico, China, and Egypt, fluctuated or have not experienced steady decreases.

In addition, the transition in household size was more erratic and abrupt among developing nations than among developed nations (Figs. 1, 2). Household size decreased in the following 28 countries and territories: Australia, Bahrain, Belgium, Brazil, Canada, China, Denmark, England and Wales, Egypt, Finland, France, Greece, Hungary, Ireland, Japan, Luxembourg, Mexico, the Netherlands, New Zealand, Panama, Philippines, South Korea, Singapore, Sweden, Thailand, Trinidad and Tobago, Turkey, and the United States (Fig. 2). In 1954, Nauru had the largest average household size in our dataset at 16.62. Sweden had the lowest (2.14) in 1990.

The number of households experienced greater increase than population growth across nations and time periods since 1800 with the exception of Ireland, England and Wales, the Seychelles, and India (Fig. 3; this trend is not visible for the Seychelles in the figure because the Seychelles' data were combined with that of Egypt in the 1950–2000 Africa column). Unusually, high population growth and social upheaval may account for these anomalies. For example, the poverty and economic exploitation that engulfed Ireland in the early nineteenth century may explain why population grew faster than numbers of households (Donnelly 2001). Similarly, when Ireland experienced population decline after the famine of the mid-1800s (Fig. 3, 1850–1900), population sizes decreased more quickly than numbers of households.

Discussion

This exploratory study supports recent calls to include households as a more central consideration in evaluation of human environmental impacts (Linderman et al. 2005; Liu et al. 2003; Peterson et al. 2013), given the potential for the demographic transition in household size to create demand for nearly a billion new homes without population growth. The results also support convergence theory, which states that household size should decrease in countries experiencing urbanization and industrialization, but with some interesting caveats. As demonstrated in other studies, we also found household size has tended to decrease from around 5 to near 2.5 (Bongaarts 2001; Goode 1963), and we found the transition occurred over nearly 100 years in developed countries ($\approx$1890–1990), but is occurring much faster in developing countries (starting in 1987). Some developing countries had household sizes near or above 10 (e.g., Nairu in 1954, Singapore in the 1940s and 1950s), and some developed countries had household sizes below 2.25 between 1980 and 2000 (e.g., Sweden, Finland, Monaco).

The causal mechanisms of household size decrease posited in convergence theory, namely urbanization and industrialization, were less clearly supported by our findings. We found that among developed nations, declines in household size occurred relatively simultaneously despite the timing of industrialization and urbanization differing by several decades among countries such as England, France, Canada, and

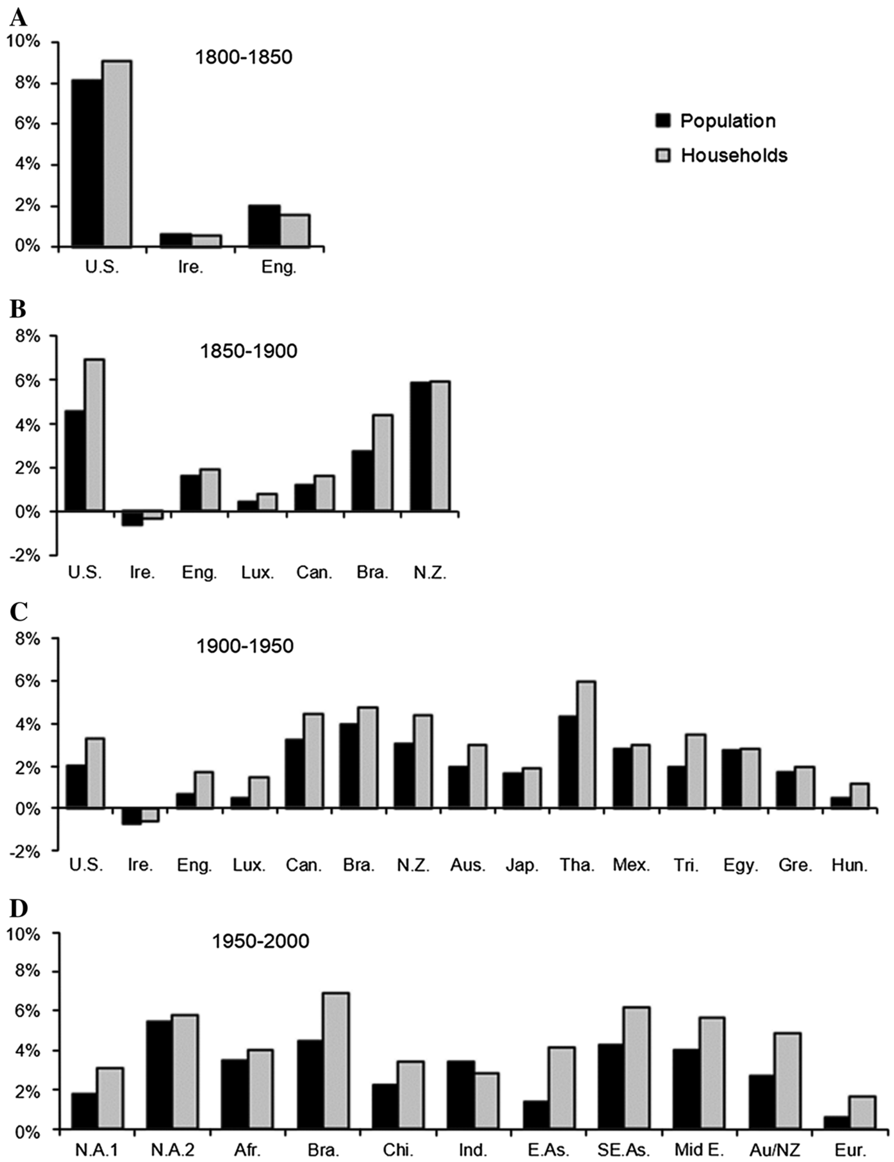

Fig. 3 Comparison of percent change in number of households and population from 1800 to 1850 (**a** United States, Ireland, and England and Wales), 1850–1900 (**b** adding Luxembourg, Canada, England, Brazil, and New Zealand), 1900–1950 (**c** adding Australia, Japan, Thailand, Mexico, Trinidad and Tobago, Egypt, Greece, and Hungary), and 1950–2000 (**d** adding N.A.1 [United States and Canada], N.A.2 [Mexico, Panama, and Trinidad and Tobago], Africa [Egypt and Seychelles], China, India, East Asia [Japan and South Korea], Southeast Asia [Philippines, Singapore, and Thailand], Middle East [Bahrain and Turkey], and Europe [Belgium, Denmark, England and Wales, Finland, France, Greece, Hungary, Ireland, Luxembourg, the Netherlands, and Sweden])

the United States. Meanwhile, declining household size among developing nations was highly erratic despite urbanization occurring as rapidly as that experienced by developed nations (Kasarda and Crenshaw 1991). The erratic nature of household size change in developing nations may be explained in part by the increasing pace of social change associated with technology and globalization (Latour 2004). Developing nations that more recently started the transition in household size would be subject to more rapid and sometimes erratic swings in economics, policy, and society in general than were developed nations in the late 1800s.

Multiple sociodemographic trends in addition to urbanization and industrialization may be associated with household size decreases. Declining fertility may be the most important immediate driver of changing household sizes (Bongaarts 2001), and may, after a time lag, contribute to declines in household numbers. Since 1950, fertility rates have fallen from 4.9 to 2.6 globally, falling 30–50 % in developed nations and over 200 % in developing nations other than those in sub-Saharan Africa where fertility rates only dropped from 6.6 to 5 during the last half of the twentieth century (World Bank 2012). Declining fertility can reduce the number of households through reduced population over long time periods, but in the short-term, household numbers go up because declines in the number of people sharing a house outpace declines in population (Peterson et al. 2013).

Aging provides one explanation for why household sizes have continued to decline rapidly even in developed countries where fertility rates have been stable for decades. Based on data from the United Nations (United Nations Population Division 2005), households with an elderly resident had on average 1.3–3.9 fewer people than those without an elderly resident in 2000. This pattern persisted across national, continental, regional, and global levels.

Whereas older people are living longer and maintaining small households longer after their children move out of households, the younger generation is contributing to household proliferation by leaving home sooner. Since the 1940s, the percent of unmarried adult children living with their parents dropped from over 70–35 % in the United States (Klinenberg 2012). This new independent life stage created 6.7 million households for unmarried people in their 20s in the US and would form 160 million new households if the same trend is expected in today's developing nations. The 'boomerang generation' of adult children returning home (a 3–4 % increase) was associated with The Great Recession of 2007 and suggests that this phenomenon may be sensitive to economic decline (Peterson et al. 2013).

The rising incidence of divorce also encourages increased household numbers. In the United States, 15 % of all households had divorced heads in 2000 (Yu and Liu 2007). Although remarriage is common, the relatively high percentage of divorced households persists (Furstenberg and Cherlin 1991), and divorced households are 27–41 % smaller than married households (households with married heads) in many nations (Yu and Liu 2007).[1] Although scholars have identified several proximate

[1] These countries are Belarus, Brazil, Cambodia, Costa Rico, Ecuador, Greece, Kenya, Mexico, Romania, South Africa, Spain and the United States.

causes for decreasing household size, there has been disagreement about the ultimate drivers behind household proliferation. Beresford and Rivlin (1966) suggested changing preferences for privacy are the ultimate drivers of declining household size, whereas others have argued that rising incomes and the relative importance of public and private household goods offer better explanation for the shift toward smaller households (Burch and Matthews 1987; Salcedo et al. 2012).

This exploratory study highlights the need for additional research exploring the mechanisms associated with declining household size. In addition to the factors discussed above, economic growth, and shifts in distribution of wealth should be evaluated as potential drivers of shifts in household size. The weak relationship between year and household size among developing countries suggests multiple mechanisms may be driving household size among some nations (e.g., political instability, natural disasters, and economic status). A slightly modified version of the I = PAT model (Ehrlich and Holdren 1971) could facilitate future research addressing the impacts of household dynamics on the environment. A basic model would be: "impact (I) = population × personal goods (P) + households × household goods (HoG; I = PHoG)." Such a model would facilitate simple calculations about the environmental impacts of changing household size and could be adapted to include goods used at other scales (e.g., water sanitation plants created at the scale of municipalities). For example, if household size falls in half from 5.0 to 2.5, and half of the resources used in a household are shared, then consumption would increase 25 % when the amount of personal goods remained stable.

Research unraveling these questions is critical not only because the topics are poorly addressed, but also because of the magnitude of potential environmental impacts of a global shift in household size. The IPHoG model suggests shifts in population size will interact with declining household size to create environmental impacts. From a more simplistic perspective, declining household sizes, from over 5 to approximately 2.5, will mean approximately twice as many houses will be needed per capita in any areas of the world yet to undergo the shift in household size. If the average household size had been 2.5 people globally in 2010, then the number of households would have been 41 % higher, resulting in 800 million additional households (2.7 billion households instead of 1.9 billion households) (United Nations Human Settlements Programme 2007). Assuming that each of the additional households occupies a 210 m^2 house (the average US house size in 2002) (National Association of Home Builders 2004), then an additional 185,800 km^2 of housing area would be required. This estimate may be conservative because land area for household-related infrastructure (e.g., roads, yards, and retail) can require 2–4 times as much land as the actual land used for the home (Allen et al. 2012). Each of those houses would demand more household products and have lower efficiency of resource use per person because fewer people share goods and services in smaller households (Liu et al. 2003). If the global trend toward household sizes of 2.5 continues, then at least 800 million additional durable household goods (e.g., televisions, refrigerators) would be needed even without population growth, assuming each household has one of each. Related transportation and residential energy costs will likely also increase.

Conclusions

This study finds decreases in household sizes across the globe, with this trend beginning later but progressing more rapidly in developing countries than in developed countries. We argue that these shifts in household size could have negative environmental impacts and policies and incentives to reduce such impacts should be considered. Improved understanding of household dynamics will allow for development of environmental and socioeconomic policies and programs to counter negative impacts. For example, rapid development of housing with separate living quarters but shared areas for eating and socializing may improve the quality of life for older singletons (Klinenberg 2012) while reducing the economic and environmental challenges posed by millions aging alone in detached single-unit suburban houses (Peterson et al. 2013). In addition to increasing numbers of households, the global trend is toward larger homes. In the United States, homes more than doubled in size between 1950 and 2002 (from 90 to 210 m^2) (based on the data from the National Association of Home Builders). In China, houses tripled in size with per capita floor space increasing from 8.1 to 26.5 m^2 and from 6.7 to 22.8 m^2, in rural and urban China, respectively, between 1978 and 2002 (Liu and Diamond 2005). Rising affluence has also contributed to sprawl, which magnifies the environmental impacts of housing by virtue of low-density development patterns that require both more land and automobile-based transportation infrastructure (Soule 2006).

In all, this exploratory study of historical trends in household numbers and size suggests it is time to go beyond population size by taking household dynamics into systematic account in population–environment research and policy, and the IPHoG model provides one tool for doing so.

Acknowledgments This work was supported by North Carolina State University, Michigan State University, and National Science Foundation. We thank B. Gardner and R. Sollmann for teaching us to use R. The research complied with the current laws of the countries in which it was performed.

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