Population and Environment (2021) 42:431–444
https://doi.org/10.1007/s11111-021-00382-w

REVIEW ARTICLE

Population responses to environmental change: looking back, looking forward

Barbara Entwisle[1]

Accepted: 16 March 2021 / Published online: 23 March 2021

Abstract

Over the past two decades, population researchers have engaged in a far-reaching and productive program of research on demographic responses to changes in the natural environment. This essay "looks back" to the origins of these developments, identifying pivotal agenda-setting moments in the 1990s and tracing the impact on contemporary research. The essay also "looks forward" to identify critical gaps and challenges that remain to be addressed and to set an agenda for future research on population responses to environmental change. It recommends that the multidimensionality of environmental contexts and change be fully embraced, long run as well as short term effects be investigated, variability in the effects of environmental change in relation to social institutions, policy implementation, and environmental context be examined, movement between contexts as well as change in situ as sources of environmental change be considered, and interconnections among demographic processes in response to environmental change be explored. Taking these steps will position demographers to contribute significantly to a larger and deeper understanding of environmental change and its consequences, locally, regionally, and globally.

Keywords Natural environment · Environmental change · Demographic response · Exposure risk · Population mobility

Although population-environment research traces its origins back several hundred years to the work of Thomas Malthus, contemporary research is no longer dominated by Mathusian perspectives. Interest continues in the effects of population size, structure, and change on the environment, but there is now equal interest in the demographic consequences of environmental context and change. This essay highlights the latter. The content grows out of the author's keynote address given at

✉ Barbara Entwisle
entwisle@unc.edu

[1] Department of Sociology and Carolina Population Center, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599-3210, USA

the conference, "Demographic Responses to Changes in the Natural Environment," held on October 24–25, 2019 at the University of Wisconsin-Madison. I argue that contemporary research in this area owes much to three pivotal "moments" in the 1990s: a 1994 request for applications (RFA) issued by the Eunice Kennedy Shriver National Institute for Child Health and Human Development (NICHD) and the National Institute for Environmental Health Sciences (NIEHS) entitled "Population and the Environment;" a 1996 workshop funded by the National Aeronautics and Space Administration (NASA) and hosted by the National Academy of Sciences on the potential of satellite data in social science research, which resulted in *People and Pixels* (NRC, 1998); and Anne Pebley's, 1998 presidential address at the annual meetings of the Population Association of America (PAA) (Pebley, 1998). In this essay, I review each of these moments, trace their impact on contemporary research, using papers presented at the 2019 conference as well as others as illustrations, and identify critical gaps and challenges that remain for future research on population responses to environmental change.

Looking back: pivotal moments

Twenty-five years ago, demographic research on population-environment interrelations was oriented toward global models and macro-comparative studies of population growth and its impact (e.g., Bilsborrow, 1987; Ehrlich & Holdren, 1971; Jolly & Torrey, 1993). It was against this backdrop, and with the vision and commitment of V. Jeffrey Evans, then a program official with the Population and Demographic Sciences Branch at NICHD, that a Request for Applications (RFA) entitled "Population and the Environment" was issued by NICHD and NIEHS in 1994 (https://grants.nih.gov/grants/guide/rfa-files/RFA-HD-95-002.html). The stated goal of the RFA was to go beyond the cross-national studies dominating the literature at that time "to establish a broad foundation for research on population/environment interrelations in a variety of geographical settings worldwide." The broader intent of the grant program funded through the RFA was to develop a new field, beginning with some case studies that were focused on developing scientifically defensible data and tools and demonstrating what could be learned through their application.[1] The RFA designated fertility, mortality, migration, and spatial distribution as population variables of key interest, and land use, flora, fauna, soil, and water quality as environmental variables of focal concern. Studies of the effect of environmental change on population processes were clearly in scope, although at the same time, "since much of the scientific debate is about whether population change or consumption and other aspects of human behavior is primarily responsible for environmental change, effort should be made to resolve this debate." Six projects were funded under this mechanism, in the US generally (Hunter, 1998), and in the US Great Plains (Deane & Gutmann, 2003), the Brazilian Amazon (Moran & Brondizio, 1998), India (Foster & Rosenzweig,

[1] Evans had had success using grants programs to jump-start research areas before, notably, in the areas of teen pregnancy, immigration, and family demography.

2003), Nepal (Shivakoti et al., 1999), and Thailand (Entwisle et al., 1998). Four of the six projects are still generating publications (e.g., Entwisle et al., 2020; Gutmann, 2018; Li et al., 2019; Williams & Gray, 2020).

Methodological work was also clearly in scope for the NICHD/NIEHS grants program, especially that pertaining to the incorporation of environmental measures into population research. In the early 1990s, then-Vice President Albert Gore encouraged the intelligence community to make satellite data and aerial maps available for scientific use.[2] Indeed, although the RFA identified the Environmental Protection Agency (EPA), the National Oceanic and Atmospheric Administration (NOAA), and the Centers for Disease Control (CDC) as likely sources of environmental data, it was the potential offered by satellite data that caught the imagination of the scientific community. This was reinforced by the 1996 workshop, *People and Pixels*, funded by NASA and organized by the National Academy of Sciences to bring social scientists and remote sensing experts together to explore the potential of satellite data in social science research, especially research on human-environment relations (NRC, 1998: vii). The workshop was the second pivotal moment of the 1990s. It is remarkable how many of the ideas and tools that remain key to contemporary population-environment research today draw from it (Balk & Grace, 2019; Kugler et al., 2019), including tools for data integration. Take locational coordinates, for example. These coordinates are essential for linking social science data to remotely sensed data, but their value and impact extend considerably beyond remotely sensed data, as they can be used to link to many other types of environmental information such as temperature, rainfall, soil conditions, water sources, and flooding potential (e.g., Chen & Mueller, 2019). Coordinates and spatially explicit data more generally opened the door to thinking about social context as rooted in space: a specific place, an environment composed of natural, physical, social, cultural, spatial dimensions (Entwisle, 2007).

The third pivotal moment was Anne Pebley's 1998 PAA presidential address. Her address sketched the history of population-environment research, described innovative research then in progress (including that funded by the grants program described above, as well as presentations from the *People and Pixels* workshop), and identified likely future directions. Pebley's address foresaw a future that was realized in many ways. Pebley identified the potential of expanding a well-established line of research on contextual determinants of demographic behavior—a line of research that she herself had contributed to (e.g., Pebley et al., 1996)—to include environmental determinants. To quote from her presidential address: "Demographic research on the environment can extend our current focus on the *socioeconomic* context of human behavior to its *physical* context (Pebley, 1998: 385, emphasis in the original)." The RFA also mentioned this as a potentially productive line of research, and the value of remotely sensed data as a source of contextual data for demographic analysis was called out in *People and Pixels* (Rindfuss & Stern, 1998), but Pebley's address brought these and other ideas to the fore. It energized the demographic research community to engage and move the field forward—and they have.

[2] Evans pointed to this, along with the National Academy of Sciences workshop on population and land use (Jolly & Torrey, 1993) and some interest by NIEHS as key to NICHD's approval of the RFA and grants program.

Where things stand now: key accomplishments

Current research on population-environment interactions traces its origins to these pivotal moments in the 1990s. Much has been accomplished since then. Although there is still room for innovation and development, the data and tools needed to explore the natural environment as a determinant of demographic outcomes are mostly available. Collecting physical locations in social surveys is now routine. For example, the Demographic and Health Surveys (DHS) have made sampling site locations available for 60 countries, from Afghanistan to Zimbabwe (https://dhsprogram.com/data/available-datasets.cfm). It is now relatively straightforward to merge environmental measures with social survey data (Boyle et al., 2020), although researchers need to be aware that survey coordinates may be displaced to protect the confidentiality of respondents. In the DHS, for example, sample clusters are randomly displaced up to 2 km in urban areas and up to 5 km in rural areas, with a further displacement up to 10 km for a random 1% of the latter (Burgert et al., 2013). Although geographic masking may affect the specific values of measures such as the Normalized Difference Vegetation Index (NDVI), the extent to which analytic results are affected by this displacement is an open question, and one pursued in this special issue (Hunter et al., 2021). More work is needed to understand the consequences of this deliberately induced error, and indeed, the consequences of the full range of strategies that have been implemented to protect data confidentiality.

As a parallel development, georeferenced measures of key environmental variables have become increasingly available. These include, for example, measures of vegetation and deforestation (e.g., Didan, 2015; Hansen et al., 2013), soils (Batjes et al., 2019), and temperature and precipitation (Funk et al., 2015; Osborn & Jones, 2014) along with spatially oriented measures of road networks (CIESIN & ITOS, 2013) and travel time to cities (Weiss et al., 2018). In the 1990s, the inclusion of remotely sensed and other physical data in social and demographic research required specialized expertise (NRC, 1998; Rindfuss & Stern, 1998). This is no longer the case. For example, IPUMS DHS recently announced a collection of environmental variables easily linked to individual and household data from DHS surveys (Boyle et al., 2020). Users without any geographic training whatsoever can include these variables in their contextual analyses of demographic outcomes. It is not unusual that when data or tools that previously required considerable training are made more broadly available, there is concern about whether new users will have sufficient understanding of the limitations of these measures (Kugler et al., 2019). These concerns notwithstanding, the potential of linking environmental variables to social survey data and using them to characterize the environmental context of demographic behavior—envisioned in the NICHD/NIEHS grants program, the *People and Pixels* volume, and Pebley's PAA Presidential Address—has been fully realized.

The tools and data needed to investigate environmental impacts on demographic outcomes are now available for many countries in the world. In addition, in line with the vision behind the initial RFA, there are some well-developed case studies, some initially funded through the NICHD/NIEHS grants program, and some not. An example of the former is the Chitwan Valley Family Study (Axinn et al., 2019), a

longitudinal study of family change in a region of Nepal that has been a rich source of data to study environmental effects on family size preferences and fertility (Biddlecom et al., 2005; Brauner-Otto & Axinn, 2017; Ghimire & Axinn, 2010) and as a separate matter, migration (Massey et al., 2010; Piotrowski et al., 2013; Williams & Gray, 2020). A study not funded as part of the NICHD/NIEHS grant program but singled out for praise from Pebley (1998) is the Indonesia Family Life Survey (IFLS), which at that time was collecting data to study the health and mortality consequences of air pollution due to forest fires (Frankenberg et al., 2005). More recently, IFLS data have been used for studies of climate shocks and fertility (Sellers & Gray, 2019) and migration (Thiede & Gray, 2017) . These in-depth studies combined with the DHS and Living Standards Measurement Surveys (LSMS) create the opportunity for rich multilevel and comparative analysis (e.g., Tobin et al., 2019).

In contrast with the 1990s, it is now possible to measure change directly on both sides of the population-environment equation. For the most part, the environmental measures listed earlier are now available for multiple time points. Rather than inferring the effects of, say, deforestation or climate change from cross-sectional comparisons of places with more forest cover or less forest cover, or more rainfall or less rainfall, responses to environmental change can be investigated directly (e.g., Li et al., 2019). On the population side of the equation, demographic surveys routinely collect retrospective information on fertility, infant and child mortality, and sometimes migration, making it possible to investigate environmental determinants in a change framework even with a single survey. Even more can be done with longitudinal panel surveys such as the Chitwan Valley Family Study, the Indonesian Family Life Survey, and the Living Standard Measurement Surveys that gather repeated measures by following the same individuals over time. For example, in this issue, Randell et al. (2021) use LSMS data from Ethiopia to show how breastfeeding patterns depend on the need for female labor during planting and harvesting, which in turn depends on the timing and amount of seasonal rainfall there. Additionally, panels of population-environment data can be constructed from administrative data. For example, also in this issue, Winkler and Rouleau (2021) put together a panel consisting of 25 years of observation on almost 3000 US counties from Census data on in- and out-migration, NOAA data on extreme heat, Federal Emergency Management Agency (FEMA) data on wild-fire related disasters, US Department of Agriculture (USDA) data on amenities, Bureau of Economic Analysis (BEA) data on wages and salaries, and Bureau of Labor Statistics (BLS) data on unemployment. Clearly, data availability is not the limiting factor it once was. Nor is the capacity to analyze and store such data.

With data and tools in hand, demographers have proceeded with their substantive agenda, undertaking studies of the effects of environmental context and change on fertility, mortality, migration, and population distribution in settings around the world. As Pebley (1998) anticipated, demographers have tended to view the natural environment as a characteristic of the larger context in which individuals and households make decisions affecting fertility, mortality, and migration. While the scope of these studies is broad, the amount of recent work on climate change and extreme natural events is particularly striking. For example, there is evidence that the timing and amount of rainfall affect fertility intentions and family planning in Indonesia

(Sellers & Gray, 2019) and, featured in this issue, children's health and nutrition in the Sahel (Grace & Davenport, 2021), and household engagement in migration in rural Thailand and Vietnam (Quinones et al., 2021). Likewise, substantial effects of extreme events such as the Indonesian Tsunami on mortality, fertility, migration, and health have been thoroughly documented (e.g., Frankenberg et al., 2008, 2011; Gray et al., 2014; Nobles et al., 2015). Demographers have been somewhat less involved in research on responses to other kinds of hazards, e.g., pollution, although this may be starting to change given the contributions of this special issue (e.g., Manduca & Sampson, 2021; Slack et al., 2021). As was true when Pebley (1998) commented on it 20 years ago, demographic research on pollution hazards is mainly concentrated on the experience of relatively rich countries, although some work is starting to emerge along these lines in the urban areas of Lower and Middle Income Countries (LMICs).

Looking forward: research opportunities

Progress has been impressive and has laid the foundation for further work on the conceptualization and measurement of environmental contexts and the variable consequences of these contexts for a host of potentially interrelated demographic and health outcomes over the short and long run. For example, demographers increasingly include multiple dimensions of the natural environment in research on outcomes linked to these environments. In this special issue, Winkler and Rouleau (2021) examine environmental amenities and disamenities in their analysis of inter-county migration in the USA. Temperature and rainfall are considered by Quinones et al. (2021) in their investigation of risk aversion and migration in rural Thailand and Vietnam. A broader conceptualization of the natural environment is a positive development—indeed, many examples could be given—and it seems reasonable to expect increasing elaboration of the natural environment as research progresses.

That said, demographers need to do more to incorporate the social *and* the natural environment in their research. Manduca and Sampson (2021) provide an excellent example of how this might be done in their study of the long-term consequences of childhood exposure to neighborhood pollution for a variety of social outcomes including intergenerational income mobility, teenage birth, and incarceration. Importantly, they consider two different exposure risks: lead paint and traffic-related air pollution. It turns out that there is not much overlap in these risks—exposures to lead paint and traffic-related air pollution are concentrated in different parts of the USA—but in other instances, exposure risks might be correlated. Even more importantly, they include social characteristics of neighborhoods (such as the poverty rate) that are likely correlated with exposure to lead paint or air pollution and that also affect income mobility, teenage birth, and incarceration. Research on the effects of chemical hazards on individual health outcomes that controls for neighborhood poverty is surprisingly rare (for exceptions, see Ailshire & Crimmins, 2014; Humphrey

et al., 2019; Kravitz-Wirtz et al., 2018). Demographers would do well to fully integrate the multidimensionality of environments in their future research,[3] as well as to consider a full range of pathways implicated in their effects.

Another fruitful avenue for future development is exploration of variability in environmental effects. Take the literature on climate change and migration, for example. Some studies document clear out-migration responses to climate change (e.g., Bohra-Mishra et al., 2014, 2017; Dillon et al., 2011; Feng et al., 2010; Marchiori et al., 2012; Nawrotzki et al., 2016). In others, out-migration response depends on resources (e.g., Call et al., 2019; Kubik & Maurel, 2016), livelihoods and the availability of adaptive responses in situ (e.g., Morrissey, 2013; Thiede and Gray, 2017), perceptions of risk (Quinones et al., 2021), and perceptions of the nature of the problem to begin with (Koubi et al., 2016). What accounts for these differences? One reason for the interest in multiple case studies in the grants program established by NICHD and NIEHS in the 1990s was the possibility that population-environment interrelationships may depend on "the institutional setting, public policy, and socio-economic behavior impinging on the place under study." Differences may also depend on features of the environmental context such as soil quality, topography, and suitability for growing various crops. There is still much to learn about contextual differences as well as individual and group differences in the effects of environmental change and the reasons for them. Indeed, the kinds of comparative analysis needed to do so, envisioned by Rindfuss and Stern (1998) in *People and Pixels*, are now possible through the joining of data from the DHS and other survey programs with comparable measures of the natural environment in multiple countries (Boyle et al., 2020).

Contextual variability can be viewed through a temporal as well as comparative lens because, of course, contexts change. Indeed, environmental change is precisely the focus. Extending arguments just made for potential differences between settings, environmental effects can also change over time. For example, the frequency of extremely destructive tropical cyclones in the Gulf of Mexico is expected to increase with climate change, even more than it already has. The consequences for the people who live there will be contingent, depending in part on community resilience (NASEM, 2019), which itself can change as the result of actions taken at the local, regional, or national levels. The effects of environmental change may also depend on who leaves, and who stays, in the affected area, assuming it remains livable. Some who live in the Gulf region now will leave, possibly in reaction to extreme events; others will migrate in and take their place (e.g., Curtis et al., 2019; DeWaard et al., 2016). Population size, structure, and composition may change as a result. One of the truisms of demography is that migration is selective. This can complicate the interpretation of environmental and other contextual effects, not only in the Gulf region but around the world.

[3] Incorporating measures of the social and natural environment may require demographers to consider potentially cross-cutting contexts, e.g., when policy-relevant units such as counties or states do not correspond to environmentally-relevant units such as watersheds.

How can we know the impact of environmental change on local populations if some of those affected have moved away? For many years, those interested in macro impacts on demographic and health outcomes at the individual level viewed mobility as a nuisance, something to be statistically "corrected." In neighborhood effects research, these corrections typically take into account selectivity related to the effects of neighborhood socioeconomic status or racial/ethnic composition. Features of the natural environment are rarely considered (see Manduca & Sampson, 2021 for an exception). Increasingly, however, demographers interested in the effects of environmental and other contextual change are approaching mobility not so much as a nuisance but as substantively interesting in its own right. And with this comes the realization that from the perspective of individuals, not only can context change in situ, it can change as a result of mobility, i.e., individuals can move to a different context, and this can have important consequences in the short and longer run. For example, in a panel study of low income, mostly African American mothers, there is some evidence that those who left New Orleans permanently after Hurricane Katrina have done better on some dimensions than those who stayed, or those who left and returned (Bosick, 2015; Graif, 2016; although see Fussell & Lowe, 2014).

Most of the recent literature on demographic responses to environmental change has focused on short-term effects, but this is starting to change. For example, Manduca and Sampson (2021) combine data from a variety of sources including Chetty's Opportunity Atlas (Chetty et al., 2020) to trace the effects of exposure to lead paint and to traffic-related air pollution in childhood, on subsequent teenage births and incarceration in young adulthood, and on income mobility in middle adulthood for US residents born in 1978–1983. Although not specifically framed this way, one might think of incarceration and teen births as potentially mediating the effects of childhood exposures on income mobility. In other words, there are multiple pathways through which exposures to pollution in childhood can affect outcomes in adulthood. Lengthening the lag thus opens the door to a myriad of potential environmental effects on demographic outcomes, direct and indirect, additive, and contingent. Panel datasets offer considerable potential in this regard, especially those underway for long periods of time. Demographers are leading many of the longitudinal studies covering a decade or more, and they are leading in the use of the data to document and explore a range of longer-term environmental effects (e.g., Frankenberg et al., 2020; Raker et al., 2019).

An underutilized framework for the study of demographic responses to environmental change is the life course perspective (Elder et al., 2003; Entwisle et al., 2020). This framework is particularly useful in the study of long-term effects. That individuals experience different environments over the course of their lives is central to the life course approach (*principle of life-span development*), as is the importance of these environments in determining a wide range of behaviors and outcomes (*principle of time and place*). These statements are consistent with many of the ideas and much of the research that has already been undertaken, as described above. In addition, the timing of exposure matters (*principle of timing*). For instance, the deleterious effects of exposure to lead paint depend on age at exposure and are most harmful for young children (Manduca & Sampson, 2021; Muller et al., 2018). As another example, it is the older residents of places hit hard by the 2004 Indonesian Tsunami

who were particularly vulnerable to its long-term effects on mortality (Frankenberg et al., 2020).

Critical to the life course approach is the notion that individuals construct their life course trajectories through a series of choices (*principle of agency*). Some of these choices specifically involve demographic processes, e.g., whether and when to marry, whether and when to have children, whether and when to move. Importantly, demographers recognize that events do not always indicate a choice, and some groups have more agency than others. This is illustrated in research on trapped versus displaced populations following disasters (Logan et al., 2016), for example, where sometimes, it is the *least* well off who *must* move, and other times, it is the *most* well off who *can* move. Movement is not only away from hazards and other negative effects of environmental change, it is also towards some alternative context which might be the same or similar to the origin context or might be quite different. In other parts of social demography, there is growing interest in neighborhood attainment, which can be conceptualized as trajectories of contextual experience (e.g., Brazil & Clark, 2017; Huang et al., 2017; Leibbrand et al., 2019; South et al., 2016). Neighborhood attainment studies focus on socioeconomic status and racial composition, but this literature could be expanded to incorporate features of the natural environment (e.g., Elliott & Howell, 2017). Finally, choices are not made in isolation (*principle of linked lives*). Individuals are linked to others who both affect and are affected by their choices and behavior, within and across generations. Incorporating social networks in the study of demographic response to environmental change points to the important role they play (e.g., Entwisle et al., 2020).

An advantage of the life course approach is that it explicitly incorporates interconnections between fertility, mortality, and migration—processes of central interest to demographers. Indeed, fuller integration of the core demographic processes would be a welcome direction for future research on environmental change and its consequences. Most of the literature is organized around dependent variables. Studies of environmental effects on, say, fertility speak to a different audience than studies of environmental effects on mortality, or on migration. The life course framework conceptualizes interconnections among demographic processes from the perspective of individuals.

The livelihood framework approaches interconnections among demographic processes from the perspective of households (De Sherbinin et al., 2008; Ellis, 2000), at least potentially. Briefly, a livelihood is a means of support to provide for the necessities of life. A livelihood strategy is a specific combination of activities in which individuals and households engage to secure a living. Households develop livelihood strategies in relation to, and in an attempt to leverage environmental endowments and other forms of human, social, physical, and financial capital to the benefit of their members in the short and long run. These strategies explicitly link environmental change to demographic response. For example, Grace and Davenport (2021) describe a household livelihood strategy in the more marginal farming areas of the Sahel based on raising animals for their cash value as well as a source of food and other products. The success of this strategy, and therefore the health and wellbeing of household members, depends on water access, which varies from place to place, time to time. Grace and Davenport (2021) focus on the consequences of environmental variability and change for child health and nutrition, but there is the potential

for other implications as well. De Sherbinin et al. (2008) use the livelihood framework to guide their review of the implications of environmental change for nuptiality, fertility, morbidity, mortality, and migration among small holders living in the rural areas of lower and middle-income countries (LMICs). Like the literature in general, their review takes up these demographic processes one at a time. To fully actualize the potential of the livelihoods framework, it is important to build bridges between demographic processes, to study them in relation to each other as multiple and interrelated responses to environmental change in LMIC's and also other settings (NASEM, 2019).

Conclusion

Three pivotal moments in the 1990s together established the foundation for contemporary research on population-environment interactions. New funding from NICHD and NIEHS helped stimulate an innovative program of research integrating social, spatial, and environmental concepts, measures, and analyses in diverse settings. The *People and Pixels* conference demonstrated the potential of remotely sensed data in the context of population research and tackled issues related to the technicalities of data integration. Pebley (1998) brought an early report on these efforts to a broad audience, combined it with her own thoughts and ideas, and energized a generation of demographers. Her PAA presidential address was particularly significant in that it promoted a contextual and multilevel approach to the study of environmental factors as potential determinants of demographic behaviors, the focus of this essay.

Much has been accomplished in the ensuing two decades. Population researchers have engaged in a far-reaching and productive program of research on demographic responses to changes in the natural environment. Data to investigate environmental effects are broadly available, environmental measures based on remotely sensed data are broadly available, and the tools needed to link and analyze them are broadly available. Although much has been accomplished, much remains to be done. This essay has pointed to some gaps and potentially fruitful lines for further inquiry. It recommends that the multidimensionality of environmental contexts and change be fully embraced, long run as well as short term effects be investigated, variability in the effects of environmental change in relation to social institutions, policy implementation, and environmental context be examined, movement between contexts as well as change in situ as sources of environmental change be considered, and interconnections among demographic processes in response to environmental change be explored. Following these directions will position demographers to contribute significantly to a larger and deeper understanding of environmental change and its consequences, locally, regionally, and globally.

Acknowledgements I would like to thank Marcy Carlson, Malia Jones, and Katherine J. Curtis for inviting me to give the keynote address for their conference, "Demographic Responses to Changes in the Natural Environment" held at the University of Wisconsin-Madison, supported in part by a grant from the Eunice Kennedy Shriver National Institute on Child Health and Human Development (R13 HD096853). I appreciate their many helpful suggestions as I developed this review essay from that address. I would also like to thank the *Population and Environment* editor, Elizabeth Fussell, for her advice about how the

essay could be improved. I am grateful to V. Jeffrey Evans for sharing the history of the NICHD/NIEHS grants program in the 1990s. Finally, I would like to acknowledge general support from the Carolina Population Center (NICHD P2C HD050924).

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