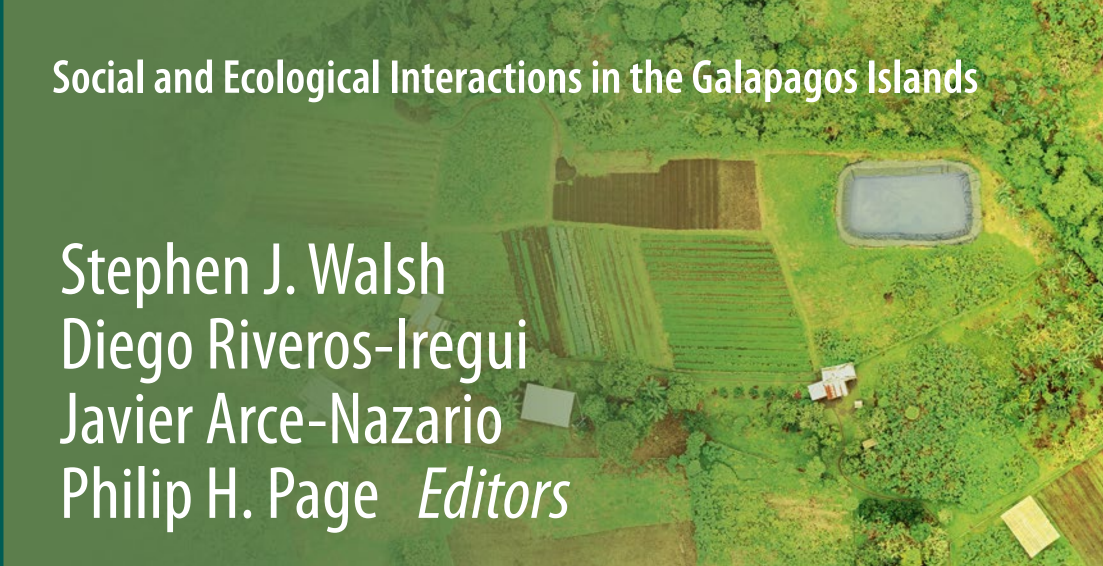

Social and Ecological Interactions in the Galapagos Islands


Stephen J. Walsh
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Philip H. Page *Editors*


# Land Cover and Land Use Change on Islands

## Social & Ecological Threats to Sustainability

Springer

# Social and Ecological Interactions in the Galapagos Islands

**Series Editors**

Stephen J. Walsh, Center for Galapagos Studies, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA
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# Series Preface

In May 2011, the University of North Carolina (UNC) at Chapel Hill, USA, and the Universidad San Francisco de Quito (USFQ), Ecuador, jointly dedicated the Galapagos Science Center, an education, research, and community outreach facility on San Cristobal Island in the Galapagos Archipelago of Ecuador. The building dedication was the culmination of an ongoing partnership between UNC and USFQ that began several years earlier through a 2006 invitation to Carlos Mena and Steve Walsh to assist the Galapagos National Park and The Nature Conservancy in a remote sensing assessment of land cover/land use change throughout the archipelago. Leveraging-related work in the Ecuadorian Amazon, Carlos Mena (USFQ Professor of Life and Environmental Sciences) and Steve Walsh (UNC Lyle V. Jones Distinguished Professor of Geography), Co-Directors of the Galapagos Science Center, traveled throughout the islands using satellite imagery and spectral and geospatial equipment to validate preliminary analyses of the Galapagos with a focus on invasive plant species. Since that project, Mena and Walsh have continued to regularly engage the Galapagos Islands on topics important to science and society and to coordinate research, education, and outreach programs conducted at the Galapagos Science Center by faculty, staff, and students from both campuses as well as by collaborating scientists from institutions around the globe. Together the UNC-USFQ Galapagos Science Team seeks to understand the complex social, terrestrial, and marine subsystems in the Galapagos Islands and their linked and integrative effects to address fundamental questions on the Galapagos and on similarly challenged island settings around the globe.

Now with over 60 park-permitted projects operating at the Galapagos Science Center and a diversity of scientific topics being studied using a host of theories and practices, innovative and transformative work continues in compelling and vital ways. The state-of-the-art facilities at the Galapagos Science Center include 20,000 square-feet of space that supports four laboratories (i.e., Microbiology and Genetics, Terrestrial Ecology, Marine Ecology, and Geospatial Modeling and Analysis), operated by a permanent administrative and technical staff to support science, conservation, and sustainability in the Galapagos Islands. In addition, students enroll in classes taught by UNC and USFQ faculty as well as conduct research to complete their undergraduate honors theses, graduate theses, and doctoral dissertations. And several scientists at the Galapagos Science Center engage the community on topics that include water and pathogens, nutrition and public health, tourism and community development, marine ecology and oceanography, and invasive species and land cover/land use change.

From these beginnings and with the general intention of developing a Galapagos Book Series to document our findings, highlight special needs, and describe novel approaches to unravel the social-ecological challenges to the conservation and sustainability of the Galapagos Islands, the Galapagos Book Series with Springer Nature was launched through its inaugural book, *Science and Conservation in the Galapagos Islands: Frameworks & Perspectives (2013)*, edited by Steve Walsh and Carlos Mena. Since 2013, the Book Series has continued to expand, with books now covering several important topics, see below:

Denkinger, J., & Vinueza, L. (2014). *The Galapagos Marine Reserve: A Dynamic Social-Ecological System*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Kvan, T., & Karakiewicz, J. (2019). *Urban Galapagos: Transition to Sustainability in Complex Adaptive Systems*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Parker, P. G. (2018). *Disease ecology: Galapagos Birds and their Parasites*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Quiroga, D., & Sevilla, A. (2017). *Darwin, Darwinism and Conservation in the Galapagos Islands*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Torres, M., & Mena, C. F. (2018). *Understanding Invasive Species in the Galapagos Islands: From the Molecular to the Landscape*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Trueba, G., & Montufar, C. (2013). *Evolution from the Galapagos: Two Centuries after Darwin*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Tyler, M. E. (2018). *Sustainable Energy Mix in Fragile Environments: Frameworks and Perspectives*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Walsh, S. J., & Mena, C. F. (2013). *Science and Conservation in the Galapagos Islands: Frameworks & Perspectives*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Walsh, S. J., Riveros-Iregui, D., Acre-Nazario, J., & Page, P. H. (In Press). *Land Cover and Land Use Change on Islands: Social & Ecological Threats to Sustainability*. Social and Ecological Interactions in the Galapagos Islands (S. J. Walsh & C. F. Mena, Series Editors). Springer Nature.

Now with considerable pleasure we welcome, *Land Cover and Land Use Change on Islands: Social & Ecological Threats to Sustainability*, edited by Stephen J. Walsh, Diego Riveros-Iregui, Javier Arce-Nazario, and Philip H. Page.

In short, the general goals of the Galapagos Book Series are to examine topics that are not only important in the Galapagos Islands, but also vital to island ecosystems around the globe. Increasingly, viewing islands as a coupled human-natural system offers a more holistic perspective for framing the many challenges to island conservation and sustainability. The perspectives used to study islands need to acknowledge the important context of history, human population, migration of plants, animals, and people, economic development, social and ecological disturbances, resource limitations, such as freshwater, and the evolution and adaptation of species (including humans) on islands to changing circumstances and conditions, both endogenous and exogenous. This book offers new and compelling insights that further adds to the Galapagos Book Series in important and fundamental ways.

Chapel Hill, NC, USA — Stephen J. Walsh
Quito, Ecuador — Carlos F. Mena

# Contents

# Prologue: Geographies of Hope and Despair: Land Cover and Land Use on Islands

**Godfrey Baldacchino**

## Introduction: The Age of Islands

Islands have long fascinated scholars, but perhaps never more so than in the current epoch of the early twenty first century, gripped as it is by the contradictory dynamics of scientific and technological progress on one hand and a viral pandemic and environmental catastrophe on the other (Bonnett, 2020). Artificial islands are built as enticing, exclusive sites of pricey real estate (Jackson & Della Dora, 2009); while other islands, and their communities, succumb to the slow yet steady threat of saltwater intrusion or sea level rise (Farbotko, 2010a). Enclave/island spaces are the new frontline spaces of development, and the emblematic sites of the Anthropocene (Pugh, 2018; Sidaway, 2007).

If islands did not exist, we would simply have to invent them. They entice outsiders: as synecdoches (whereby a part is made to represent the whole): as "prototypical ethnoscapes" (Baldacchino, 2007a, p. 9); and as handy, manageable and scaled-down reproductions of (larger and messier) continents (Kirch, 1997). The smaller islands get, the simpler and the greater the imputed convenience of this 'island-mainland' correlation. No wonder, therefore, that scientists—often outsiders—descend Gulliver-like upon (smaller) islands to identify, witness, observe and then depart, while inferring and deducing cause-effect relationships, which they acknowledge as writ large in larger (read mainland) contexts (Baldacchino, 2008, p. 42). It is as if islands have been ordained and disposed to act as "outposts of globalisation" (Ratter, 2018); and as advance indicators or extreme reproductions of what is present or future elsewhere (Baldacchino, 2007b). No discipline has been spared from this exercise; but zoologists (think Charles Darwin, Rosemary Grant),

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bio-geographers (Jared Diamond, Rosemarie Gillespie) and anthropologists (Bronislaw Malinowski, Margaret Mead) probably lead the pack with their proclivity and enthusiasm for such island fieldwork and *in situ* observation (Baldacchino, 2006).

## Illusionary Beacons of Stability

The self-evident physicality of an island offers a beguiling expression of stability: a piece of land surrounded by water, crafted by God and/or Nature. And yet, this staid condition of islandness is illusory; the picture-perfect image is transient (Kelman, 2018). First, this is because of the natural cycles of geological and environmental change, which sculpted the island in the first place: from volcanic eruptions, coral growth, or the erosion of erstwhile connected peninsulae and promontories. Cycles of vegetation, and their accompanying fauna, are replaced in succession. The same forces can and do eventually lead to the wholesale disappearances of such islands, though not necessarily in our lifetime (Whittaker, Fernández-Palacios, Matthews, Borregaard, & Triantis, 2017).

A second cause is the impact of the human species on its natural environment, readily visible in island features. Land is reclaimed to extend surface area; sand, stone and gravel are shifted to design or better protect harbours and coastlines; bridges are built to connect islands, and to connect islands to mainlands; in which case, some might say that they are no longer islands (Royle, 2002). Swamps drained, mines quarried, hills levelled, forests felled, river courses dammed and altered … with modernity, history has transitioned into one continuous and open-ended struggle to force landscape and geography to succumb to human intent. (Some would add greed.) As with French writer Albert Camus when he visited the island of Manhattan, it would be easy to forget that this "desert of iron and cement" is actually an island (Camus, 1989, p. 51). In this mission of "culture as development," humans play a significant part in transposing or abetting the movement of species from one ecosystem (where they may have evolved naturally) to another (where they may find themselves in different predicaments, ranging from being hugely disadvantaged to finding themselves in dominant positions and with fewer or no natural predators) (Quammen, 2012).

A human-mediated spread of invasive, non-native species drives biodiversity loss and habitat degradation all over the planet, but these consequences are nowhere as stark as on small islands, with their fragile ecosystems (with native and endemic species having evolved in splendid isolation from predators, diseases and competitors) as well as with strained and limited human resource skill and expertise pools. Already in the heydays of colonialism, islands were savagely transformed into platforms for monocrop economies (think tobacco, sugarcane, banana, pineapple), or sites for the planned transfer of invasive species, driven by the whim to reproduce, say, the idyllic English countryside (Grove, 1995; Royle, 2007). Such small islands may be hotbeds of biodiversity; but, barring extreme measures of access limitation or prevention—not easy to impose, as the recent history of the Galápagos archipelago reminds us—they are *not* likely to withstand or escape the impact of humanity over time. References to a 'balance' between conservation and development are often euphemisms disguising serious issues of ecological degradation (Mathis & Rose, 2016). Whatever traces of 'nature' can be found in such disturbed enisled spaces, the best we can hope for are "human gardens": seemingly natural, but actually constructed scapes (Picard, 2011). On most small islands, we need to acknowledge that we live in a "post wild world" (Marris, 2013).

Size and scale conspire to make such changes appear even more dramatic (Fordham & Brook, 2010; Hay, Forbes, & Mimura, 2013; Kerr, 2005; Kier et al., 2009; Kueffer et al., 2010; Pelling & Uitto, 2001; Spatz et al., 2014), a dynamic also described as "articulation by compression" (Brinklow, 2013). For the first time ever, cityscapes now represent the homes of the majority of humanity (Berry, 2015); but, on small islands, such urbanisation has led to exceptionally heavy population densities, and therefore a greater propensity to sprawl and physically connect island urban zones with contiguous islands or mainlands (Grydehøj, 2014, 2015). Many of the world's capital cities, built originally on islands to afford better protection from attack, have outgrown their protective defensive walls and possibly eliminated the aquatic border, now an irritating barrier to expansion, that separated them from nearby land (Baldacchino, 2014).

## Islands and Density

Islands that are political units are also geographical enclaves that tend to have higher population densities than mainlands, also because offloading people across the sea remains a more problematic, and definitely more dangerous venture than distributing them across land borders onto a neighbouring land mass. Moreover, around half of humankind dwells on or near coastal regions, because continental interiors are disadvantaged locations for settlement. Amongst island states and territories, subnational island jurisdictions (SNIJs) tend to be even more attractive spaces for in-migration than sovereign island states, even though they tend to have a much smaller land area (Armstrong & Read, 2003; McElroy & Pearce, 2006).

At the risk of serving as a paean to positivism, the much higher mean population density for islands than for continents is supported by the statistical evidence. Excluding the large (but practically empty) land mass of Greenland—for all its land area of 2 million km$^2$, its resident population is around 55,000—the world's island units have a mean population density of 144 persons per km$^2$: this is *three times* the mean value of 48 persons per km$^2$ that works out for Eurasia, America, Africa and Australia combined; and excluding Australia would only make a marginal difference (see Table 1).

Islands occupy just 1.86% of the Earth's surface area; and this percentage drops down to just 1.47% if one again excludes Greenland. However, they are the

**Table 1** Population density on islands and continents compared (2010 data)

| Land Mass | Population (A) | Land Area ($km^2$) (B) | Population Density (A/B) |
|---|---|---|---|
| 1. Four continents | 6,550,400,000 | 136,071,330 | 48 |
| 2. As (1) above, less Australia | 6,530,000,000 | 128,453,330 | 51 |
| 3. All island states and territories | 588,800,000 | 6,263,612 | 94 |
| 4. As (3) above, less Greenland | 588,700,000 | 4,088,000 | 144 |

Source: Baldacchino (2011, p. 168)

**Table 2** The 13 states and *territories* (in italics) with the highest population density (of more than 2,000 persons per square mile) for base year 2010 (*rounded figures*)

| Rank | Jurisdiction | Of which, islands | Resident Population | Area($mi^2$) | Density(/$mi^2$) |
|---|---|---|---|---|---|
| | World (land area only) | | 7,100,000,000 | 57,510,000 | 123 |
| 1 | *Macau (People's republic of China)* | Partly | 546,200 | 11.3 | 48,450 |
| 2 | Monaco | | 33,000 | 0.75 | 44,000 |
| 3 | Singapore | Fully | 5,077,000 | 274.2 | 18,510 |
| 4 | *Hong Kong (People's republic of China)* | Partly | 7,008,900 | 428 | 16,380 |
| 5 | *Gibraltar (UK)* | | 31,000 | 2.6 | 13,260 |
| 6 | Vatican City /Holy See | | 1000 | 0.17 | 5880 |
| 7 | Malta | Fully | 410,000 | 122 | 3360 |
| 8 | *Bermuda (UK)* | Fully | 65,000 | 20 | 3250 |
| 9 | Bangladesh | | 164,425,000 | 55,598 | 2960 |
| 10 | Bahrain | Fully | 807,000 | 280 | 2880 |
| 11 | Maldives | Fully | 314,000 | 115 | 2730 |
| 12 | *Guernsey (British Isles)* | Fully | 65,700 | 30 | 2180 |
| 13 | *Jersey (British Isles)* | Fully | 91,500 | 45 | 2040 |

*Source*: Baldacchino (2011). Jurisdictions *in italics* above are self-governing units and not independent states

collective home to some 10% of the world's population: almost 600 million people (Baldacchino, 2006, p. 3).

Gross mean figures of population density—calculated as the mid-year resident population per unit of land area—can be misleading, since various regions in the world are inhospitable to human life and populations tend anyway to cluster and aggregate around coastal regions, riverbanks, ports and sources of fresh water. Still, several of the most densely populated territories in the world are city-states and small jurisdictions (see Table 2). Their residents share a relatively small land area, high levels of urbanisation, relatively high levels of economic prosperity but accompanied by relatively high levels of environmental degradation. Many tend to be peninsular or island units, preventing a natural spillover of population across contiguous

**Table 3** Discrete (unbridged) islands with very high population densities (over 2000 persons per square mile)

| Population Density (per square km) | Island Unit |
|---|---|
| 820 | Oreor (Palau) |
| 830 | Losap (Federated States of Micronesia) |
| 840 | Kili (Marshall Islands) |
| 840 | New Providence (Bahamas) |
| 900 | Moen (Federated States of Micronesia) |
| 920 | Java (Indonesia) |
| 1000 | Tarawa (Kiribati) |
| 1000 | Funafuti (Tuvalu) |
| 1130 | San Andrés (Colombia) |
| 1260 | Malta (main island of Maltese islands) |
| 2460 | Majuro (Marshall Islands) |
| 5180 | Malé (Maldives) |

*Source*: Baldacchino (2011)

borders. The glaring exception is Bangladesh, the only country in the world with a large (and relatively poor) population and a high population density: at least 100 million people there are at risk from the effects of (even moderate) sea level rise (Islam & Van Amstel, 2018).

Some of these jurisdictions, like Jersey, are single island entities. Others boast a number of island units, in which case a mean national population density often conceals more extreme statistics at the sub-state level. This is most evident in the cases of Malé, capital island of the Maldives, and home to some two-thirds of that country's population. Others include New Providence (capital island of the Bahamas, and location of Nassau), Moen (capital island within Chuuk, one of the four Federated States of Micronesia), Majuro (capital island atoll of the Marshall Islands), South Tarawa (main atoll settlement within sprawling Kiribati), Malta (main island within the Maltese islands) and San Andrés (a sub-national island jurisdiction of Colombia). In each of these cases, population densities are much higher than their respective national mean figures. Many of the world's most densely populated islands are to be found amongst South Pacific archipelagic states (see Table 3). All of these, except Java, Indonesia, are small island units.

## Empty Islands

If one is looking for extreme cases of population density, islands offer ample examples from *both ends* of the density continuum. Indeed: island jurisdictions do not just provide scenarios of very high population density, with places like Bermuda, Malta and Singapore topping the list. They also throw up examples of delineated land areas with very low or zero population density: islands - including the island continent of Antarctica - offer the *only* examples of completely de/unpopulated, geographically discrete and self-identifiable areas on the globe: every other type of landform—montane, steppe, desert, valley, forest, river delta, taiga, tundra …—is at some point physically connected to another. Not islands: "'uninhabited' is a word attached only to islands" (Birkett, 1997, p. 14). In their 'emptiness', such island locales are attractive, and in sometimes very contrasting ways. One enticement could be the exploitation of their (often unique) natural qualities and apparent 'underdevelopment' or 'pristine' state for the purpose of identifying, and then protecting, nature reserves, possibly harbouring rare, threatened and/or endemic species. After all, nature reserves are "habitat islands" in any case (Pickett & Thompson, 1978). Such island spaces are easier to protect from the curious or adventurous. Another, contrasting attraction could be the use of such islands, especially depopulated ones, as locales for offshoring undesirable "waste" (human or material) and dangerous experiments: an "enforcement archipelago" that includes detention centres for refugee claimants, high security prisons, quarantine stations, nuclear waste dump sites and high-risk scientific test facilities (Mountz, 2011).

## Islands as Tourism Destinations

Pressure on land is greatly exaggerated on islands, also because many of them have transitioned organically into tourism destinations (Carlsen & Butler, 2011). Many islands come with unique cultural or natural specificities; and so these locales become attractive places to visit (Harrison & Hitchcock, 2005). The obligatory crossing over water (by air or by ship/boat) becomes part of the catharsis associated with the spiritually or mentally cleansing journey over water to an island 'paradise' (Patton, 2007). It is no wonder, therefore, that almost a sixth of UNESCO's World Heritage Sites—115, at the latest count—are found on islands, or are islands *in toto* (World Heritage Sites, 2019). And yet, the pressure of visitor numbers threatens the sustainability of the tourism industry, especially on small islands (Apostolopoulos & Gayle, 2002; Lim & Cooper, 2009). Tourism aggravates the crowding and pressure on basic resources (transport, water, energy, foreshores …) and introduces an additional and different set of land use and sea/landscape stakeholders into the bargain. Overwhelmed by their own galloping success in attracting visitors, and miffed by the failed promises of mega-projects gone horribly wrong (Lippert & McCarty, 2016), small islands scramble to manage tourism numbers as best they can: encouraging small scale eco-operations; closing tourist sites for 'maintenance' (Dickinson, 2019); and mounting hostile displays against tourists, while claiming the right to 'take back' their island (Dodds & Butler, 2019). In pursuing the mantra of eco-tourism, small islands may also invest in inefficient or ineffective renewable energy and sustainability initiatives so as to hold on to an illusory eco-island status, thereby ensnaring themselves in an eco-label (Grydehøj & Kelman, 2017).

There are many initiatives underway in the name of small island sustainability; but progress is slow and may shift scarce resources and policy attention from other, more pressing concerns (Baldacchino & Kelman, 2014). Working towards sustainable development can be elusive in small islands (as well as in small island and archipelagic states) because this is fraught with multi-scalar challenges. These include limited biodiversity, extensive in and/or out-migration, pressure of tourism visitations, external interventions and protocols, scarce human resources, weak management systems, inadequate data (and problems of interpretation), social divisions and tensions (often invisible to outsiders) and simultaneous quests for modernity and conservation (Connell, 2018). Moreover, small islands by definition thrive and survive by inputs (including in-migrating species) derived from beyond their shores: it comes as no surprise that Cuba, long subjected to a trade embargo, was feted by the World Wildlife Fund in 2006 as the only country on the planet anywhere close to sustainability (Guevara-Stone, 2008).

## Prospects

Nearly a quarter of all sovereign states are islands, and islands have taken the lead in the development of innovative forms of governance (Felt, 2003; Stratford, 2006), environmental management, and in the development of alternative energy technologies (Hay, 2006, p. 20). Meanwhile, from Tuvalu to the Venice Lagoon, islands have become the nostalgic targets of a sadistic streak of 'dark' tourism, invaded by visitors attracted to such places while they remain accessible, and indirectly contributing to and hastening their demise with their carbon footprint (Farbotko, 2010b; Hindley & Font, 2017).

If any traces of optimism are to be found in the pages of this book, then it may be the sophisticated capture of data that steals the show. From the Hawaiian islands and the Galápagos, to Montserrat and Sulawesi, more powerful and yet more affordable technology has provided important datasets that capture the state of environmental degradation, ecosystem service disruption, loss of forest cover, increase of land dedicated to agriculture, and the penetration of non-native invasive species. One can also better overlay and integrate different classes of data to approximate the multifaceted and integrative nature of environmental change, and at various spatial scales. It is already possible to compare the state of today's islands with their condition in the distant, or not so distant, past: again, small islands can demonstrate radical landscape changes over relatively short periods of time. The expectation is that, armed with the science and the data, and the visual 'before and after' imagery that they permit, policy makers are better convinced and equipped to make the case and to implement measures that brake, or perhaps even revert, the consequences of rampant globalisation and consumerism. Islands may yet present themselves as geographies of hope, rather than of despair.

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# Economic and Related Aspects of Land Use on Islands: A Meta Perspective

**Richard E. Bilsborrow**

## Preface

This is the first of two studies that seek to distill the recent extensive and growing socio-economic literature on island land use and factors related to it and its changes over time, focusing on methodological aspects and contributions. This chapter will briefly describe the full scope of the eight topics covered, including the four larger ones focused upon in this chapter plus the four topics to be covered in a separate but companion study (covering population, urbanization, tourism, and climate). We recognize, however, that they there are inherently *many interrelationships* across and within not only the four broad topics focused upon in this chapter but with the other four topics as well—all relevant to understanding the evolution of changes in land use on islands over time in the recent past and in the future and factors underlying these changes.

Although my personal interest and experience is on developing countries, I do attempt to include here references on islands which are not developing countries if they have broader methodological interest. Islands reviewed here include almost continent-sized islands such as Madagascar and large islands of Indonesia and the Philippines, though most will be small in size, from all of the non-polar oceans. I generally exclude the literature focused on the measurement of land use itself or the technology of remote sensing/satellite-based data and methodologies employed, which is reviewed separately in this volume (see Chapter 3 by Walsh, et al. and case studies). Exceptions are studies on LCLUC measured from remote sensing which have a significant substantive, social science focus. Hawaii is an integral part of the United States so is not covered here, and coverage of Puerto Rico and the Galapagos Islands is also limited as they are covered directly in other chapters of this book. Finally, none of the extensive, so-called grey literature nor government documents nor publications of international agencies is covered in this review.

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## Methodology for and Scope of Literature Review

The procedure for conducting the literature search and evaluations began with computer searches by topic (using multiple key words combined with land use) of various academic literature databases, using criteria for initial filtering to delete short/popular literature references and a wealth of specialized scientific literature from the natural and physical sciences. Finally, from what remained, more subjective criteria based on the topics focused upon here and my own multi-disciplinary interests albeit with inevitable biases were used to pare it down to an almost manageable body of relevant publications since 1990, and available in English (see Appendix for details). Abstracts were then obtained for as many of these as possible (over 90%)—around a thousand for the eight topics altogether, about 600 for those covered in this chapter), and then skimmed to identify those for which full texts were sought and usually obtained, which constituted the tier 1 references, with the rest constituting tier 2 (see table in Walsh et al., chapter 3 above). However, upon careful reading of the full articles or further reading of the abstracts at the time of writing for each topic, many abstracts stimulated me to re-categorize them as tier 1 (and therefore of inclusion in the text here as well as the references), while a number of the tier 1 items were downgraded to tier 2. Moreover, some items were re-classified as more appropriate for the second, companion study focusing on population, urbanization, tourism and climate (in preparation, but not part of this book). These time-consuming processes resulted in somewhat over 100 publications covered in this meta-analysis, and cited at the end of the chapter. The full bibliography for all eight topics, after further paring down at the second time of reading abstracts stage, eliminating duplicates, and cleaning up references to be of similar format, comprises about 700 items (vs. over 950 originally found and shown in the Walsh chapter above), and is available from the author or editors on request.

The time reference is generally from 1988 to 2018, when this review began. Doubtless important new publications have come out since then, which should be borne in mind by readers of this book. The overall goal was to identify analytical studies that include insightful descriptions of linkages between land use and socio-economic factors as well as those using interesting or novel methodologies to link the particular topic to land cover use and land use change (*LCLUC*).

For further details, see the Appendix to this chapter.

The map below (Figure 1) illustrates the location of the islands and the number of studies on each from tiers 1 and 2 combined for all eight topics from the initial classification of over 900 studies. It shows the concentration on various islands as expected (Puerto Rico, Hawaii, Madagascar, with 55, 49 and 18 studies on each, respectively), but more than expected on some islands, including more on Indonesia (especially Sumatra with 18) than on the Philippines, and a fair amount on Jamaica and St. Lucia in the Caribbean; on Hainan (China), the Galapagos Islands, the Solomon Islands, Fiji and Vanuatu, in the Pacific (16 down to 8 studies on each); Mauritius, nearby Reunion, and Zanzibar, in the Indian Ocean; the Canary Islands, Madeira and the Azores, in the Atlantic; and Lesvos (Greece), Malta and Mallorca (Spain), in the Mediterranean.

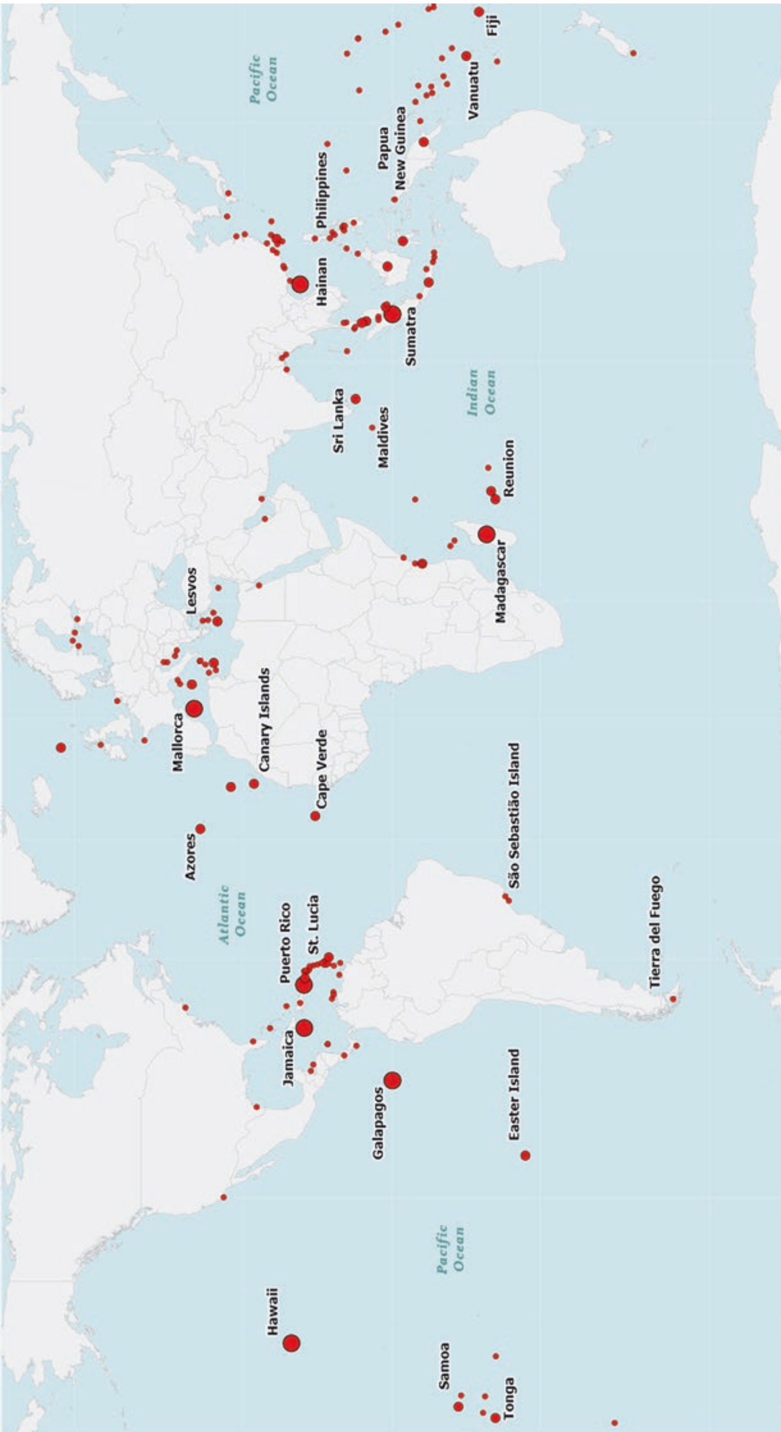


**Fig. 1** Study area location

As mentioned above, this chapter of the book will cover the recent literature relating to LCLUC focusing on its relationships to economic and/or other social science factors, involving quantitative or qualitative approaches and mathematical or statistical modeling of linkages. The measurement of LCLUC will usually but not always be via remote sensing. While many of the studies reviewed deal with more than one of the four topics here combined with land use, as the topics are interrelated, I have separated them according to what I perceive as the *primary* focus, which sometimes is not always what is implied by the title of the publication. As the reader peruses the inevitably brief descriptions of each publication, it should be clear what the key related topics are (both among the 4 categories here as well as from among the four topics to be covered in a companion study—population, urbanization, tourism and climate). This should assist the reader interested in finding additional references relevant to a particular topic. No formal comprehensive cross-referencing was possible here, such as by stating at the end of a topic, see also authors x, y and z cited under topic X below.

The meta-analysis in this chapter is organized under four numbered topics below, with short summaries or conclusions at the end of each topic, noting some of the highlights and weaknesses of the literature.

- Topic 1. Linking Agriculture and Forest Cover to LCLUC
- While there is a substantial recent literature on these topics in the Amazon and elsewhere, what is there on Island States and other islands? From remote sensing, there is considerable data on the patterns and changes in LU over time for most islands, captured in measures of deforestation and reforestation, which have usually been identified as linked to the expansion of agriculture for food production, expansion of export crops, or intrusions into protected areas (with the impacts of expansion of urban areas into forests or agricultural lands to be covered under urbanization in the companion study).
- Topic 2. Economics and Economic Models of Land Use
- This will include all types of analyses involving economic variables, from those at the macro/economic sector levels based often on economic census or national accounts data down to household/farm/firm based data at the micro level, including those with linkages with other economic sectors/topics. This will include both statistical and econometric studies, in which the statistical model used, relevant dependent and independent variables, and main findings will be described briefly when available in the original source, along with key parameters found.
- Topic 3. Land Use on Islands and Broader Links to Socio-economic Factors
- This section deals with the broader social-science literature focusing on factors affecting LCLUC, including the literature on remote sensing measures of LCLUC treated as the dependent variable.
- Topic 4. Other Models of Land Use and Unusual Approaches
- This section attempts to pull together a wider range and variety of modelling approaches towards linking LCLUC to factors that are not primarily economic, or more oriented to culture and policy.

## Topic 1. Linking Agriculture and Forest Cover to LCLUC

Over the course of the past 10,000 years since the beginnings of agriculture with the domestication of wheat in Mesopotamia and corn in the central valley of Mexico, the expansion of agriculture has been central to human progress and population growth. It made possible converting from hunting and gathering to agriculture as the main source of sustenance, converting forests, shrub and grasslands to food crops, to the settling of populations in small stable communities and ultimately towns and cities. This in turn led to the creation and advance of civilizations over the recent millennia. With the industrial revolution, over the past two centuries or so, this has involved considerable rural-urban migration, with vast shifts in population from rural to urban areas, with the urban population now reaching 55% of the world total. Increasing urban and total populations require more food, from more agricultural products, as well as greater exploitation of forests for fuel, housing and food, both transforming land use across the planet. Much of the expansion of the land area planted in agricultural products has historically come from clearing forests (along with clearing grasslands, shrubs, etc.,) constituting the *extensification* of agriculture (which neo-Malthusians associate with Malthus). With the advancements of technology including the science of agriculture, agricultural production has also expanded via the *intensification* of agriculture (Bilsborrow & Carr, 2001; Bilsborrow & Geores, 1992, 1994; Boserup, 1965). This expansion has made possible the vast increase in human populations over the past two centuries, *pari passu* with the expansion of industry, services and technology, including vast advances in transportation, communications and desires for better lives, involving vast trade in goods and services across countries and oceans including the international migration of people and capital. Islands have been a part of all these processes as well. This section will focus on recent shifts in agricultural and forest areas in islands and their interrelationships.

A host of related topics and socio-economic and biophysical variables related to either or both agricultural changes and changes in forest cover are found in the island literature, but have been filtered out of the discussion in this chapter due to their being less centrally linked to land use *sui generis*. These include (unless explicitly linked to land use) water supply/hydrology/ground water/aquifer depletion; studies of a particular crop or tree species; invasive species and species extinctions; coral reefs and mangroves; mining; gender roles; fire; volcanos; soil erosion; river sedimentation; cultural and political studies, etc. There do exist investigations focusing on all of these topics and more that we encountered in the literature search, with many in the tier 2 references not generally included in the review here (see Appendix). On the other hand, we did seek to cover under this topic logging and fuelwood use in relation to land use; small farm and plantation agriculture; reforestation; protected areas (forests, not reefs); geographic and geophysical aspects of land; locations of fields, farm houses and forests relative to transportation networks, market towns and cities; population size, growth and density in relation to land use; rural labor opportunities and unemployment (under topic 2). Alas, we shall see that on many of these topics there is little recent analytical/quantitative research on islands found here.

As is well known, by now there has emerged a considerable recent literature on agriculture, land use and deforestation in developing countries, especially in the Americas and Asia, most examining impacts of agricultural expansion on forest cover. These studies were summarized in an earlier meta-analysis by Geist and Lambin (2002) and Lambin et al. (2001); have included a number on the Amazon region, including Brazil and Ecuador (e.g., Keller, Bustamente, Gash, & Silva Dias, 2009; Pan & Bilsborrow, 2005; Walker, 2004), Thailand (Walsh, Entwisle, Rindfuss, & Page, 2006). Several studies of economists have examined causes of tropical deforestation with economic and econometric models (e.g., see Brown & Pearce, 1994; Kaimowitz & Angelsen, 1998). But what evidence is there on Island States and other islands?

The literature review here is organized by geographic region, beginning with the Caribbean region, followed by Asia (mostly the island countries of Southeast Asia and islands next to China), then the many mostly small Pacific islands spread across the vast Pacific), islands along the two ocean coasts of Africa (led by Madagascar), and finally a category Other referring to relevant special studies on islands of developed countries. This is the geographic sequence followed for this topic as well as the other three topics in this chapter.

### *Caribbean*

We begin with Jamaica, then cover other islands generally also experiencing deforestation, and conclude with the exceptional case of Puerto Rico, which has been undergoing an extraordinary long-term process of reforestation.

Two particularly intriguing, quantitative studies on Jamaica are by Tole (2001, 2002)and Newman, McLaren, and Wilson (2014), both combining and integrating data from satellite imagery with socio-economic-population data, covering different parts of Jamaica and at different times. Both also seek to ascertain the causes of its substantial deforestation. As Newman et al. note (p. 186), “despite the concentration of land cover change studies from the Latin America region, drivers of change in Caribbean islands have been largely understudied”. Jamaica has had one of the highest rates of deforestation in the region over the past 30 years or so. Tole (2002) combines MSS satellite imagery from 1987 and 1992 with population census data to examine human factors contributing to loss of forest cover in 1987–92. She describes her approach as a meso-study, intermediate between analysis of household or plot level data and macro or province-regional level data, saying it has the advantage of greater detail than macro studies while providing more generalizable results than data from households in a small geographic area. During her study period, Jamaica was experiencing serious economic and social problems (inflation, high unemployment, growing debt, declining public spending), together with almost 1% annual population growth. MSS data with pixel sizes of 57m × 57m, or about 4 times those of Landsat TM, for its 51 constituencies, were used as units of analysis since they were available for the whole island, including urban centers. Data for characterizing the populations of the 51 areas were compiled for households from the 1992 population census and a 1998 World Bank-supported Jamaica Survey of Living Conditions. Euclidean distance to the nearest of the five principal urban areas from the constituency centroids were computed; population density was estimated from census data divided by land area; and other variables were computed for mean dependency ratios, house quality, education, fuel use, and poverty. OLS (Ordinary Least Squares) linear regression results are not very strong ($R^2$ from 0.2 to 0.4), with deforestation positively linked to "social welfare" (more deforestation where people were poor, more dependent on fuelwood, and had higher population density and age-dependency), but also linked to higher male education. Despite the weak results, the study was innovative for the region in integrating use of satellite and population census data, making use of what data were available. This could evidently be emulated in many other islands as most have some data of both types--satellite imagery and population census data.

Newman et al. (2014) deals with a far smaller area, of only 68,024 ha in Cockpit Country in the west-central highlands, where forest reserves constitute half of the area. The site is one of very high biodiversity in plants, frogs and birds. They investigate not only socio-economic drivers but also biophysical conditions; by controlling for the latter, they can isolate effects of the former. The area overall is not densely populated, has mostly small farms under 2 ha, with farming the main occupation, growing some subsistence crops but mostly yams for export. Biophysical features including forest cover were available from area photographs at 6m resolution for a series of years from 1942 to 2010. They sought out as many potentially useful explanatory variables as possible, based on the discussion in Geist and Lambin (2002), but were limited in the end to population density (census population, as in Tole, but divided by the district area, for much smaller areas than constituencies); Euclidean distances to towns and capital cities; relative wealth/poverty level (based on primary water source, sanitation, lighting source, fuel use and house tenure); plus education and employment/unemployment. Using logistic regression to measure whether forest cover rose or fell in each district in various 10 to 20- year periods, the authors concluded that *long-term deforestation* (over the whole 68 year period) was primarily determined by *biophysical and geographic* factors, specifically the terrain (slope), existing forest fragmentation at the beginning of the period (forest contiguity index), and Euclidean distance from nearest road to forest edge. These results are not surprising. At the same time, socio-economic factors were more important in the shorter-term decadal periods, notably employment status, population density, age-structure of community population, and main water source as an indicator of wealth: Thus lower densities of households were associated with *higher* land clearing, surprisingly. The authors noted that land clearing was also linked positively to the proportion of adult women, and therefore absent men, with the latter engaged in non-farm work, returning to clear forest for farming when they could not find jobs. The linkage between clearing and lower population density may be explained as follows: when men work in non-farm occupations, they earn higher incomes, some of which is taken back to the origin households and invested in acquiring more land and/or clearing existing land they have in the origin, mainly to expand cash crop agriculture. Overall, the statistical results are not particularly strong and sometimes surprising for economic and demographic variables, they are strong for biophysical-geographic factors, with similar results for factors determining *reforestation.*

Before getting to Puerto Rico, several studies note an unusual, relevant land characteristic of much of the Caribbean islands referred to as *Caribbean karst*, common throughout the Greater Antilles as well as the Bahamas, Antigua, Cayman Islands, Virgin Islands, Guadeloupe, Barbados, Trinidad & Tobago, and the Dutch Antilles. The karst is difficult to farm, and includes towers, sinkholes (*cenotes*, in Yucatan, Mexico), caves, etc. Karst lands are also prone to both drought and flooding, fragile and subject to environmental change, though with care can provide long run agricultural goods (Day, 2010). Their particular vulnerable characteristics should be taken into account in land use planning. Unfortunately, humans have instead damaged them greatly, destroying natural vegetation, contaminating water, and using them as quaries. Climate change, increasing temperatures and changing weather with overall decreasing precipitation is also disrupting the karst hydrological cycle, leading to increasing desertification. Population growth and economic growth are likely to further threaten the karst-based ecosystems, unless improvements are made in land management and planning to ensure long-term sustainability.

Chopin and colleagues (2014, 2015) have undertaken intriguing research on the French island of Guadeloupe. In the 2014 study, seeing farmers having a poor understanding of desirable crop rotation patterns, the authors first assess the evolution of crop acreages over time and space, to develop a dynamic typology of farmers to classify their multi-year use of land in seven steps, 3 based on farm typology, 3 on landscape changes, and one on factors influencing those changes. They apply the method to 3591 farms, identifying 8 farm types according to crop acreage size, and then use it to describe the process of diversification of 111 sugarcane growers into fruits and vegetables, noting their dependence on water availability. They say their 7-step method could be used to measure ecosystem services associated with changes in agriculture at the landscape level as well.

In the second paper, Chopin et al. develop a multi-scale bioeconomic model for the classification and assessment of cropping systems at the field (plot), farm, sub-regional/community and regional scales to provide cropping system mosaics for regional optimization of the sum of individual farmer's utilities under field, farm and regional biophysical and socio-economic constraints. Dubbed MOSAICA, they say it can be used in different regions with data on the location of the field and farm, on cropping system yields, on locational characteristics and on policy schemes. The model is applied in Guadeloupe (Chopin et al., 2015) to test the impacts of three alternative policy scenarios of agricultural subsidies, producing three cropping system mosaics in which the area under traditional bananas and sugarcane was transformed into breeding better varieties plus other higher value crops. The entire cropped area of the three small islands constituting Guadeloupe is only 32,948 ha, containing 7749 farms with a mean size of 4 ha, ranging from under 1 to over 100 ha. The model requires extensive data down to each plot size, which was available for over 70% of the farms from a geodatabase of fields from the government agency providing farm subsidies. Data are needed on input use and yields ideally for all plots to generate data for optimization. 36 cropping systems for Guadeloupe were identified from previous work, synthesized into the 8 farm types of the topology cited above. Risk aversion coefficients were postulated for each type. The geographic database includes field biophysical traits and farm structure data from the agricultural census, and the Delphi method is used to develop other parameters based on seeking and synthesizing expert opinions. The objective function is based on Markowitz-Freund to maximize regional utility over the whole population of farms, subject to certain biophysical limitations due to karst soil conditions, etc. Several interesting policy scenarios were then experimented with, including the effects of eliminating subsidies for sugarcane and bananas, as required by the World Trade Organization by 2017 (within 3 years). Results generally predicted sharp declines in those two crops along with increases in areas in pasture, fallow, fruit orchards and vegetables. Differential effects of scenarios on agricultural revenues, food self-sufficiency, crop diversification, employment, soil and water quality, etc., were investigated. Strengths lie in the model's capacity to provide rich results for forecasting/planning, but the data needs are huge, farmers' decisions have to be simplified, parameters are static, etc. The authors note also that the model would benefit from being linked to other models incorporating markets and economic sectors. Ones I would also specifically suggest, include tourism and the external sector (exports, imports, foreign aid, and remittances from migrants). But these suggestions result in far more additional complexity. While the model is not construed as a research model, MOSAICA could be used, as is characteristic of models, to identify needs for further research to obtain more reliable model parameters for itself, as well as other models (e.g., input-output, risk parameters).

Finally, the island which has been far and away the most studied in the Caribbean is Puerto Rico, which, following massive deforestation in the first half of the twentieth century due to human population growth and clearing for agriculture, has undergone a sustained, major *reforestation* during the second half. While reforestation was known to be going on before, we begin with the article of Rudel, Perez-Lugo, and Zichal (2000) as it provides an excellent descriptive analysis, beginning with the striking fact that the forest cover, which had shrunk to 9% of the island by 1950, rose to 37% by 1990. To put this in context, as elsewhere in the region, the island was largely covered in forest (majority in sub-tropical moist forests) at the time of European contact. The land was then converted primarily to export agriculture—coffee for Europe, sugar for North America, and tobacco for the US cigar market. By 1930, the country was largely cleared of forests with a dense rural population and considered a Malthusian problem, with a population of 2.2 million in 1950—denser than almost all European countries. 80% of the rural residents were landless, working as wage laborers on export crop plantations and farms. Between 1950 and 1990, the population grew by 1.3 million, while the country reforested. How did this happen?

The authors draw on data for individual land plots from a Forest Service inventory in 1990: the country was overlaid with a grid of 3km × 3km pixels from which a systematic sample of aerial photographs were taken of 1 ha plots at intersection lines of the grid. This was followed up with ground truthing (not explained beyond "visits"), eliminating urban land and primary forests, leaving 675 plots of land. The other, principal sources of baseline data on human activities were from the 1950 census of population and the 1959 agricultural census, which, like most, collected data on farm size, tenure, crops grown, off-farm employment and the most valuable crop in the community closest to the intersection point. Data were aggregated to characterize each *municipio* as primarily coffee, sugarcane or tobacco communities, or reforesting. Logistic regression was used to determine the factors responsible for re-forestation, of both one ha plots and *municipios*. Independent variables examined were elevation, mean farm size in the *municipio* in 1959, proportion of farms with off-farm income or mean off-farm income, percent change in population, poverty (% households with under $500 annual income in 1959 or 1978), mean expenditures on fertilizer, and an interaction term of coffee x precipitation. In the regression based on regional measures (n = 69 *municipios*), reforestation was found positively linked to elevation, the coffee-precipitation linkage (proportion of existing land in coffee and high precipitation), off-farm work, and poverty; and negatively to farm size, with the results similar in a parallel regression for small one-ha plots, except for an additional strong negative effect of population growth and no effects of poverty or off-farm work. Thus rural population decline was a major factor in reforestation (see also discussion of agricultural abandonment in Parés-Ramos et al. 2008) —consistent with the observed substantial rural-urban migration in the 40 year period, linked directly to rapid industrialization and higher wages. This latter finding is consistent with (and perhaps inspired?) the "forest transition" hypothesis associated with Rudel et al. (2002), in which reforestation is expected to occur as a country develops through industrialization which stimulates rural-urban migration over time. However, as noted by the authors, Puerto Rico also has an unusual relationship with the United States, facilitating migration to the mainland and the sending of substantial remittances back, which doubtless contributed to the process.

Among notable other studies that followed are those of Helmer (2004), Lugo (2002), Marín-Spiotta, Ostertag, and Silver (2007), and Yackulic et al. (2011). Helmer used data from air photos in 1977–78 and Landsat TM images (30m × 30m pixels) to examine the biophysical and geographic factors associated with "land development", or conversion from non-urban use (forest, shrub, agriculture) to urban use. Using logit models (pixel converted or not), she found the major factors to be the type of initial land use including type of forest cover if forested, elevation, and, especially, accessibility and proximity to an existing urban area. She predicted that ecological zones near the coast are most at risk of being converted unless new, strictly protected reserve areas are established to preserve them. No socio-economic data or variables were examined. In a second paper, Lugo (2002) examines the evolution of tree species (new, alien as well as native species) in Puerto Rico over time during the process of reforestation, finding new species achieving dominance early in the process, but providing some protection for regeneration of native species (as "refugia"), so that by 60–80 years, reforested stands have similar species richness as native stands. However, they have fewer endemic species and lower soil carbon and litter, and accumulate above-ground biomass as well as soil carbon more slowly. This is also the topic of study in Marin-Spiotta et al., who examine changes in plant species composition as abandoned pastureland in southeastern Puerto Rico was naturally regenerated by secondary forest species (5 types) over periods of 10, 20, 30, 60 and 80 years. The highest accumulation of above ground biomass (carbon) was during the first 20 years, and by 80 years secondary forests had greater biomass than primary forests due to replacement of woody species by palms. Overall, the new ecosystems had similar species richness, and higher potential for carbon sequestration than remnant primary forests, perhaps a small positive sign for climate change amelioration if generalizable to other secondary forests.

The final study here on Puerto Rico, of Yackulic et al. (2011), examines the effects of both biophysical and socio-economic factors on the forest transition, but again based on ecological (micro area—not household or farm-level) data, over the periods from 1977–1991 and 1991–2000. They found biophysical factors (slope, rainfall, surrounding land cover) most important in determining reforestation at the *municipio* level (n=78) in the first time period, with reforestation driven by abandonment of less productive, steeper farmlands, mostly in west-central parts of the island. But these factors had little explanatory power at the smaller scale *barrio* (n=875) level. The importance of socio-economic factors (only variables studied being mean income and population density) was stated by the authors to be higher in the second time period, but still neither variable reached statistical significance on either reforestation or deforestation. The process of rural-outmigration to suburban and urban areas—a central aspect of population dynamics, according to other studies above—was not captured by these two static variables. More important, the model might have investigated the effects of changes in population and incomes *over time* on the dynamic process of changes in forest cover, though perhaps data were sought but not found. Finally, areas with protected areas experienced significantly less deforestation, as is to be hoped.

The last study is on the Pacific coast of Costa Rica (Kull, Ibrahim, & Meredith, 2007), which has also successfully undergone reforestation, for totally different reasons (due to good policy, not forced by endogenous processes of development as in Puerto Rico) reflecting successful synergies between international conservation ideologies, tourism which stimulated real estate investment for infrastructure, and modest migration for livelihood diversification. Though these same forces involving tourism have been present in, for example, Madagascar—noted in the publication—such a positive evolution has not occurred there, as we see later in reviewing forest cover and its changes in the context of Africa. Thus, it is possible for globalization to stimulate positive changes in the form of reforestation linked to tourism, though this may simultaneously increase social marginalization and inequality, as noted in this paper.

One overall conclusion from the Caribbean studies is that the quantitative ones either only studied biophysical variable effects on land use change or, when