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Global Rates of Habitat Loss and Implications for Amphibian Conservation

ALISA L. GALLANT, ROBERT W. KLAVER, GARY S. CASPER, AND MICHAEL J. LANNOO

A large number of factors are known to affect amphibian population viability, but most authors agree that the principal causes of amphibian declines are habitat loss, alteration, and fragmentation. We provide a global assessment of land use dynamics in the context of amphibian distributions. We accomplished this by compiling global maps of amphibian species richness and recent rates of change in land cover, land use, and human population growth. The amphibian map was developed using a combination of published literature and digital databases. We used an ecoregion framework to help interpret species distributions across environmental, rather than political, boundaries. We mapped rates of land cover and use change with statistics from the World Resources Institute, refined with a global digital dataset on land cover derived from satellite data. Temporal maps of human population were developed from the World Resources Institute database and other published sources. Our resultant map of amphibian species richness illustrates that amphibians are distributed in an uneven pattern around the globe, preferring terrestrial and freshwater habitats in ecoregions that are warm and moist. Spatiotemporal patterns of human population show that, prior to the 20th century, population growth and spread was slower, most extensive in the temperate ecoregions, and largely exclusive of major regions of high amphibian richness. Since the beginning of the 20th century, human population growth has been exponential and has occurred largely in the subtropical and tropical ecoregions favored by amphibians. Population growth has been accompanied by broad-scale changes in land cover and land use, typically in support of agriculture. We merged information on land cover, land use, and human population growth to generate a composite map showing the rates at which humans have been changing the world. When compared with the map of amphibian species richness, we found that many of the regions of the earth supporting the richest assemblages of amphibians are currently undergoing the highest rates of landscape modification.

AMPHIBIANS occupy important, mid-trophic level positions within most tropical, subtropical, and temperate ecosystems (reviewed in Whiles et al., 2006), and therefore reports of declining amphibian populations worldwide are alarming (Blaustein and Wake, 1990; Houlahan et al., 2000; Alford et al., 2001). Although many factors contribute to amphibian declines, either singly or in combination, biologists throughout the world agree that principal causes include habitat loss, alteration, and fragmentation (Blaustein and Wake, 1995; Green, 1997; Noss et al., 1997).

Amphibian interactions with habitat are species dependent and variable, but certain characteristics make them particularly sensitive to environmental changes. Amphibians are ectothermic and have permeable skin; they rely upon their external environment for regulating body temperature and moisture loss (Duellman and Trueb, 1986; Zug et al., 2001; Pough et al., 2004). In addition, most species have a complex life history, requiring both wetland and terrestrial

habitat components at different seasons or life stages. Therefore, habitat requirements are multiple and can be complex, making amphibians extremely susceptible to landscape alterations (Beebee, 1996, 1997; Alford and Richards, 1999).

Although the availability of habitat does not indicate species presence, the lack of habitat most certainly corresponds with species absence. There is worldwide evidence that habitats are being destroyed or altered at rates that exceed our ability to document and study species (Wilson, 1988, 2002). Agriculture often supplies the motivation. It is the leading cause for loss of wetlands (Baldassarre and Bolen, 1994), which provide important breeding habitat for many amphibian species. Available data are too incomplete to support reliable estimates of the global extent of wetlands and wetland loss (Finlayson and Davidson, 1999), but approximately half of the world's wetlands have been lost in the last 100 years (Myers, 1997). More than 5,000 km² of wetlands are lost each year in Asia

through agriculture, water withdrawal for irrigation, and dam construction (Myers, 1997). Overall, draining and conversion to agriculture has reduced wetland area in Europe by 60% (United Nations Development Programme et al., 2000). In the conterminous United States, 53% of wetlands were lost between the time of Euro-American settlement and the mid-1950s, with an additional 2.5% loss between 1974 and 1983 (or 117,450 ha/yr; Baldassarre and Bolen, 1994). Loss of wetlands has not been uniform throughout the United States; by 1990, 22 of 50 states lost more than 50% of their original wetlands, and 11 states lost more than 70%.

Agriculture is also the leading cause of grassland loss and deforestation. Current grassland extents range from ~9% of original cover in the North American Great Plains, to ~73% of original cover in the Central and Eastern Mopane and Miombo Woodlands of Africa (White et al., 2000). As much as 50% of the original extent of tropical forest has been lost since the 1970s, resulting in destruction of habitat, isolation of fragments of formerly contiguous habitat, and edge effects between forested and deforested areas (Skole and Tucker, 1993). Achard et al. (2002) noted that between 1990 and 1997, 2.3 ± 0.7 million ha of tropical forest were visibly degraded (e.g., fragmented, burned, logged, converted to savanna or woodland) each year. Skole and Tucker (1993) reported that the rate of fragmentation and degradation for the Brazilian Amazon was more than twice that of deforestation between 1978 and 1988.

The relation between human population growth and loss of amphibian habitat is easy to understand. People alter the landscape through their needs for food, shelter, fuel, and livelihood, by their lifestyle choices, and through the development of settlement infrastructure (Heilig, 1994; Ricketts and Imhoff, 2003). The localized changes brought about by human activities have direct effects on amphibian habitat availability, quality, and function, but add up to regional and global significance when climatic, hydrologic, and atmospheric characteristics are affected (Meyer and Turner, 1992; Bonan, 1999; DeFries et al., 2002; Marshall et al., 2003), which, in turn, feed back on the local habitat conditions. In fact, the increasing globalization of human activities means that the linkages between socioeconomic activities and supporting ecosystems are so geospatially decoupled as to be operating at a planetary scale (Folke, 1996).

In the past century, since roughly the beginning of the Industrial Revolution, human population has grown nearly exponentially (Meffe and Carroll, 1997), although more recently, rates

have been slowing for most of the world (Lutz et al., 2001). Human population growth is expected to end before 2100, with a total global population exceeding 14 billion (Lutz et al., 2001). There will be regional differences to the patterns of population change; developed countries are expected to have population declines earlier in the century than developing countries (Lutz et al., 2001). Human populations in both North Africa and sub-Saharan Africa are expected to double in the next two decades, while those in Eastern Europe and the European portion of the former USSR are predicted to decline (Lutz et al., 2001). China and South Asia currently have approximately equivalent populations, but by the middle of the 21st century China is projected to have about 700 million fewer people than South Asia (Lutz et al., 2001).

In order to provide a geographic context to the problem of global amphibian declines and add perspective to the challenge of amphibian conservation, we assessed the pattern and magnitude of landscape change at the global scale and compared it with the pattern of amphibian species distribution. We compiled information on agricultural and forest variables, human population growth, and amphibian distribution to generate a set of maps depicting the rates at which humans are changing the landscape and the regions of highest activity.

MATERIALS AND METHODS

To compare amphibian distribution with patterns of habitat loss and alteration at a global scale required a set of maps. To derive a map of amphibian distribution, we principally consulted published literature and databases and used a broad-scale ecoregion framework to help integrate information across the variety of scales and approaches by which amphibian distributions have been described. To map rates of landscape change we pursued temporal information on human population growth and statistics on land use and land cover, again using an ecoregion framework to interpret patterns.

Ecoregions.—A framework for analyzing patterns, rates, and consequences of land use dynamics is most suitable when it has been derived from variables that affect or reflect how humans interact with the landscape (Gallant et al., 2004). Accordingly, we sought a set of ecoregions that would capture the broad-scale interplay between environmental characteristics and anthropogenic activities (i.e., ecoregions synthesized from information on climate, landforms, geologic formations, soils, hydrologic regime,

vegetation, and past and present land use and land management). Such frameworks have been developed for North America (Omernik, 1987; Gallant et al., 1995; United States Environmental Protection Agency, 2000), and extended to the western hemisphere (Griffith et al., 1998), but a comparable set of ecoregions has not been mapped for the eastern hemisphere.

To compile an ecoregion map for the eastern hemisphere we used a framework developed by Bailey (1989) because the general methodology was documented and the map was available digitally. Bailey's map was not delineated using the same protocols and combinations of environmental variables used to delineate ecoregions in the western hemisphere, but we attempted to overcome some of the differences by aggregating regions from his finest level of hierarchy into coarser units that were more comparable in environmental representation and scale with the coarsest level of hierarchy depicted for North America by the Commission for Environmental Cooperation (1997) and for Central and South America by Griffith et al. (1998). We consulted a number of continental-scale thematic maps to help us in this task.

Amphibian species richness.—Distributions of amphibian species richness were mapped initially using information provided in Duellman (1999), then modified using data presented on AmphibiaWeb (<http://amphibiaweb.org>; as of March 2007) and gathered for the recently completed Global Amphibian Assessment (<http://www.globalamphibians.org>; as of September 2005). In the United States, data were mapped from a digital national amphibian atlas database (Lannoo et al., 2005; these maps formed the basis for the U.S. data used in the Global Amphibian Assessment). Ideally, species richness should be mapped using geospatially consistent data. In reality, information on amphibians is unevenly available around the world. This is apparent in how contributors to Duellman's (1999) book opted to report species distributions; in some cases, species numbers were reported based on political units (country, state, province, etc.), while in others, various types of regional units (e.g., physiographic regions, vegetation regions, natural regions, etc.) were used. This inconsistency is also apparent (but was minimized) in the Global Amphibian Assessment and on AmphibiaWeb. The digital database developed by Lannoo et al. (2005) for the United States offered the finest detail in spatial units.

To map species distributions outside the United States, we tried to use the most reasonable mapping unit, depending on how the

information was provided. For example, information reported at the level of a country often could be refined to the portion of the country associated with the appropriate ecoregion; species descriptions were consulted to determine ecoregion affiliation. In this manner, we could map a species that occurs in, say, tropical forests to the region of the country supporting tropical forests. In cases where countries were smaller than ecoregions (e.g., in Central America), we used the country boundaries to map amphibians, rather than assuming their distribution extended beyond the country to the remainder of the ecoregion. We strove to make decisions that were conservative for mapping species distributions. To create a final map of species richness, we needed to overcome the global inequities in the amphibian record while still retaining the ability to depict relative patterns of richness. We accomplished this by organizing the total number of species into seven classes of increasingly larger ranges of species richness (e.g., 1–10 species, 11–20, 21–40, . . . , 161–320, and 321–640). This allowed us to portray patterns of the relative magnitude of species richness around the world, without being hampered by the handful of species that might not yet have been described for the more depauperate areas, or the dozens to hundreds of species that might not yet have been described for the richer areas.

Human population growth.—Population data were compiled from several sources. We used data from the World Resources Institute (United Nations Development Programme et al., 2000) for mapping contemporary rates of change in human population growth in five-year increments from 1950–2000. For a longer-term perspective (1850–1950), we relied largely on McEvedy and Jones (1978), supplemented with information from web sites such as University at Utrecht online library (<http://www.library.uu.nl>; as of May 2006) and GeoHive (<http://www.xist.org>; as of May 2006), sites with geopolitical data and human population statistics. Two challenges in mapping human population distributions are that countries and boundaries change over time and different sources of population statistics rarely agree (though they are usually similar). For the latter issue, we consulted miscellaneous references to help determine which of our principal sources offered the best estimate for a given area.

Land use dynamics.—Maps of land cover and land use were generated based on a tabular database obtained from the World Resources Institute (United Nations Development Programme et al.,

TABLE 1. LAND USE AND LAND COVER THEMES MAPPED USING DATA FROM THE WORLD RESOURCES INSTITUTE (UNITED NATIONS DEVELOPMENT PROGRAMME ET AL., 2000). Layers used to generate a composite map of change are marked with an asterisk.

Theme	Temporal range of data	Rationale for use in the composite map
*Mean annual percent change in human population growth rate	1950–2000	Used most recent rates (1995–2000) of growth
*Percent change in closed canopy forest	1996 compared with estimated pre-settlement extent	Offered the best information of the available forest cover variables.
Percent change in natural forest cover	1990–1995	Not used. Data not available for many countries.
Percent change in total forest cover	1990–1995	Not used. Too inclusive, everything from natural forests to plantations and savannahs.
*Number extirpated and threatened tree species	as of 1990s	Used as surrogate for change in vegetation composition.
*Percent change in cropland area	1961–1997	Used as indicator of land cover conversion to agriculture.
Percent change in agricultural production	1961–1997	Not used. Production rates can be affected by many factors, including sociopolitical decisions (e.g., subsidies), weather, and chemical applications.
Percent change in permanent cropland	1961–1997	Not used. Represents within-state change of annual crops to woody crops. Both are agricultural usage.
*Irrigated acreage as a percentage of total cropland	1961–1997	Used as surrogate for water quality and wetland habitat. Irrigation can lower water table (drying nearby wetlands and reducing stream flow) and increase chemical concentrations in return flow to waterbodies.
*Mean annual fertilizer use	1961–1997	Used as surrogate for potential exposure of amphibians to agricultural chemicals.

2000). The database included country-level statistics of land use activities or land cover characteristics related to agriculture and forests (Table 1). These data have been compiled from an amalgam of sources that represent a wide variance in data availability, consistency, and quality (United Nations Development Programme et al., 2000; Pimm, 2001).

Because political reporting units (in this case, countries) mask patterns relating to ecological characteristics, we refined the country-level data with maps depicting within-country patterns of land cover. A global land cover characteristics product derived from 1992/1993 satellite sensor data (Loveland et al., 2000) enabled us to geographically improve the mapping of country-level statistics for the 1990s. That is, we applied agricultural statistics to the places where agriculture occurred. We did the same for forest statistics, with the exception that we applied information on the number of lost tree species to entire countries, as we had no way of knowing what parts of the countries these species previously occupied.

To gain a composite perspective on rates at which humans have been modifying the landscape, we selected a subset of maps (Table 1),

including rates of recent (1995–2000) human population growth, changes in agricultural practices (cropland area, irrigation acreage, and fertilizer usage), and changes in forest cover (closed canopy forest area and number of extirpated or endangered tree species), and examined the degree to which these variables co-occur. We transformed the values for each map to range from 1–5 and calculated an average to represent relative rate of change.

RESULTS

Ecoregions.—At the global scale, our resultant map included 21 ecoregions (Fig. 1). The map provides a reasonable product for a global assessment, but there are some ecoregions in the eastern hemisphere that are not represented as well as we would have liked, an artifact of our having modified an existing map that did not capture environmental characteristics in the same manner as the maps we used for the western hemisphere. Major examples are that the boundaries for the Tropical Rainforests Ecoregion have too great an extent in India; the boundaries for the Arid Lands Ecoregion in

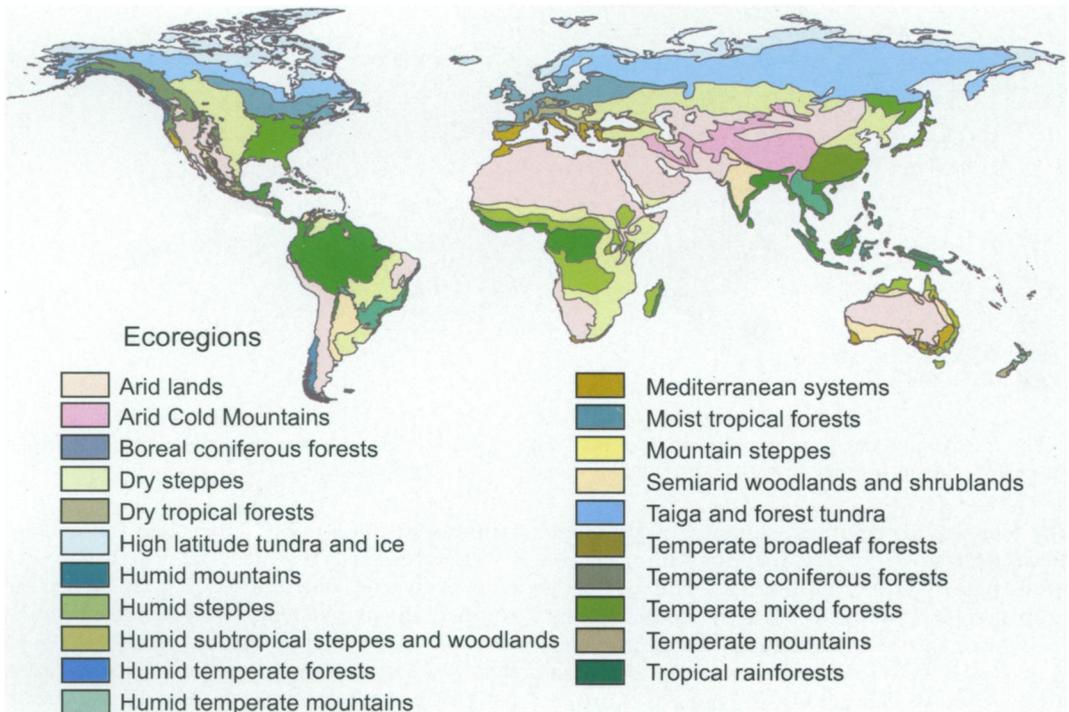


Fig. 1. The 21 ecoregions used in this assessment (note that Greenland and Antarctica have been excluded because they lack amphibians).

Africa are so broad as to mask distinctions among hyper-arid, arid, and some semiarid ecosystems; the Arid Lands Ecoregion in Africa includes fingers into Ethiopia, Sudan, Kenya, and Tanzania that do not correspond with environmental patterns depicted on continental thematic maps (so, these extensions are questionable at the global scale); and the Taiga and Forest Tundra Ecoregion incorporates more ecosystem variability in northern Europe and Asia than we would have delineated.

Worldwide distribution of amphibians.—Amphibians are not distributed uniformly across the surface of the earth (Fig. 2). Humid ecoregions, such as the Tropical Rainforests, Moist Tropical Forests, and Humid Subtropical Steppes and Woodlands (Fig. 1), support a rich amphibian fauna, while drier ecoregions, such as the Arid Lands, Arid Cold Mountains, Dry Steppes, and Semiarid Woodlands and Shrublands, and colder ecoregions, such as the Boreal Coniferous Forests, support relatively few species.

Human population change.—Maps of human population growth for the intervals between 1850–1900, 1900–1950, and 1950–2000 show that higher growth rates were concentrated away

from the lower latitudes during the first half of the 1800s, but over time shifted towards the lower latitudes (Fig. 3). Patterns of high human population growth rates now occur in latitudes more favored by amphibians (Fig. 2).

Conversion to agriculture.—A map highlighting recent changes in closed canopy forests (i.e., exclusive of open woodlands and savannas) shows that rapid deforestation is still pervasive (Fig. 4A). A map showing the number of tree species that were estimated to have been lost or considered threatened (Fig. 4B) indicates a decrease in vegetation diversity that is exceptionally high in a number of countries. In many cases, these are countries that correspond with regions of high amphibian richness (Fig. 2).

Worldwide, we found that rates of change in agricultural production varied widely in the second half of the 20th century (map not shown). Certain patterns of change adhered to ecoregion boundaries within continents (e.g., >150% increase in rates of agricultural production in the Moist Tropical Forests and Dry Steppes ecoregions of China, mild increases in the Semiarid Woodlands and Shrublands and Tropical Rainforests ecoregions in India, and mild increases in the Semiarid Woodlands and Shrublands and

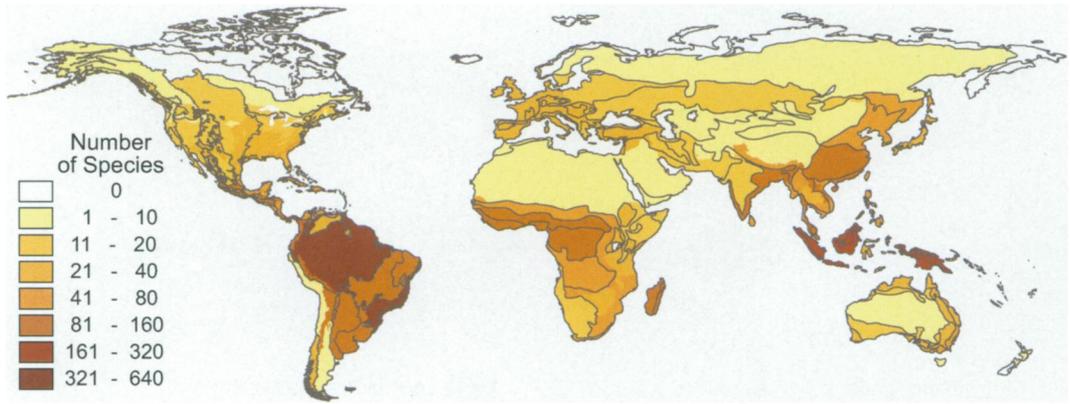


Fig. 2. Amphibian species richness. The map legend depicts classes of species richness, where each successive class represents twice the number of species as the previous class.

Dry Steppes ecoregions in Argentina), although there were no consistent patterns within ecoregion types across continents. The area in cropland increased in most agricultural regions of Central and South America, Africa, Asia, and Australia, but there were decreases in cropland area in most ecoregions in western Europe (Fig. 5A). Similarly, agricultural areas throughout the world experienced increases in permanent crops (i.e., orchards, vineyards, plantations, and other crop types not requiring replanting following harvest), with parts of Europe being the main exceptions (map not shown).

Irrigated agriculture and fertilizer use have also been on the rise. Between 1961–1997, the proportion of irrigated cropland increased in most agricultural areas, including the Dry Steppes Ecoregion, the Semiarid Woodlands and Shrublands Ecoregion (but not so much in North America), the Moist Tropical Forests Ecoregion, and the Tropical Rainforests Ecoregion in Asia, Madagascar, and portions of Central America (Fig. 5B). Patterns of increased fertilizer usage mirrors that of increased irrigation, with dramatic increases in fertilizer (thousands to >140,000%) recorded for the regions in China, Turkey, Southeast Asia, South America, and portions of Africa (Fig. 5C).

Composite rates of change.—The map generated by integrating information on human population, forest vegetation, and agricultural activity shows rates of change ranging from very low to very high (Fig. 6).

DISCUSSION

As a rule, amphibians prefer warm, moist habitats, and so for any given longitude species

richness will tend to be higher near the equator and lower towards the poles, as evidenced in our map of species distribution (Fig. 2). When we compare the map of amphibian richness with the composite map of landscape change (Fig. 6) there is a disturbing correspondence between patterns of high species richness and patterns of high rates of change, particularly in the Tropical Rainforests, Moist Tropical Forests, and Temperate Broadleaf Forests ecoregions. Many of these same areas are still undergoing moderate to high rates of human population increase.

Our maps support observations made by others regarding overlaps between regions of high human population growth and biodiversity hotspots (Pimm and Raven, 2000; Stuart et al., 2004). By 1995, biodiversity hotspots (including prime amphibian habitat) covering 12% of the Earth's landmass contained nearly 20% of the world's human population (Cincotta et al., 2000). Hotspots have a population density of 73 people per km², compared to 42 people per km² for the world average. Human population growth rates within these hotspots are significantly higher than the population growth rate of the world as a whole, and even greater than that of developing countries. Mittermeier (1986) described "major tropical wilderness areas" consisting of tropical forests in Upper Amazonia/Guyana Shield, Congo Basin, and New Guinea/Melanesian Islands covering 6.3% of the Earth's terrestrial habitat. Currently, these areas are inhabited by 1.3% of the world population (Cincotta et al., 2000), and the human population growth rate of 3.1% per year within these areas is more than twice the global rate (Cincotta et al., 2000). Our maps of population growth for five-year intervals from 1950–2000 (not shown) corroborate the geographic shifts in population predicted by Lutz et al. (2001). During this 50-

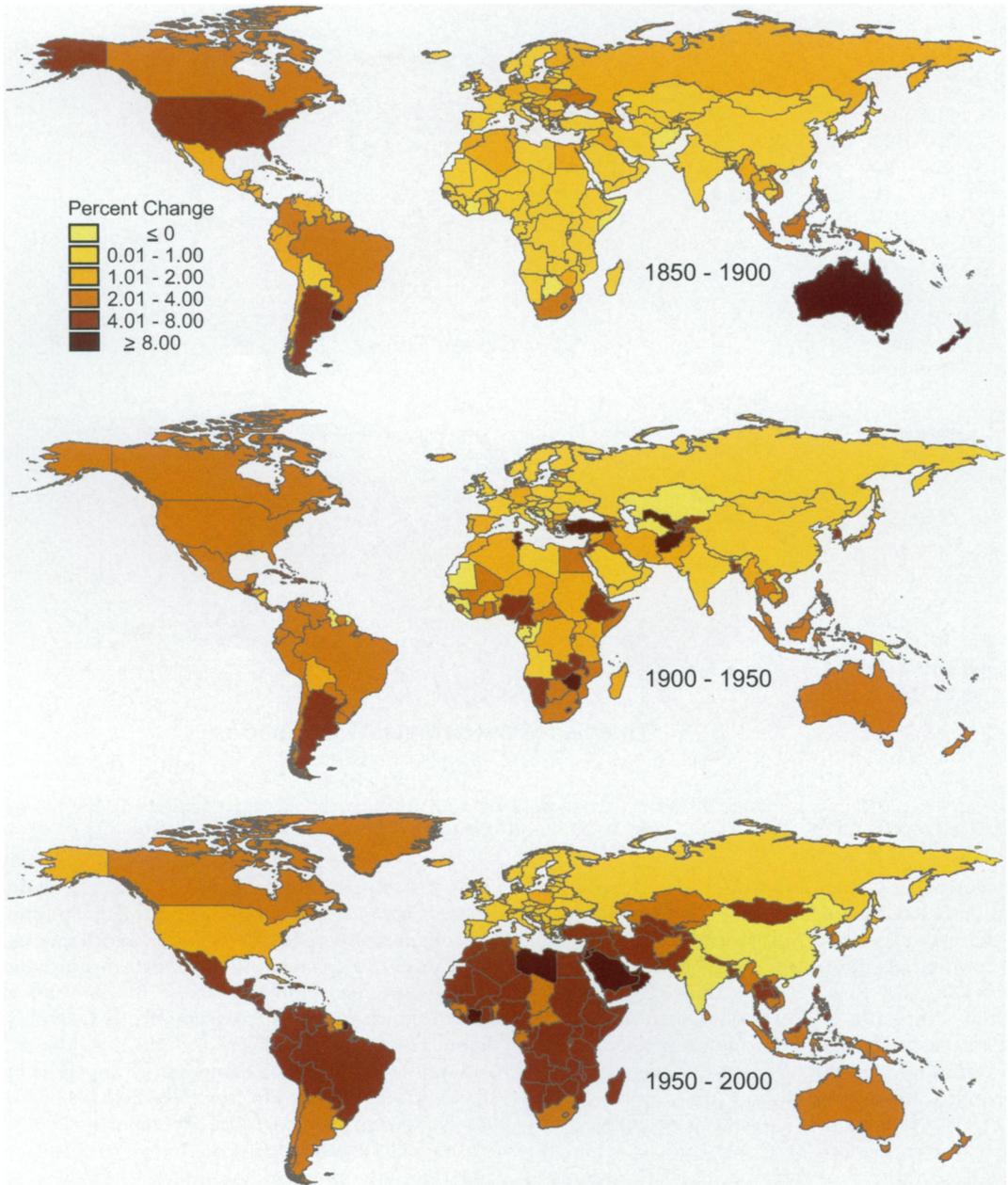


Fig. 3. Maps of human population growth rates for three time intervals. There is a general decrease through time in growth rates for countries in temperate and higher latitudes in contrast to a substantial increase in human population growth rates in tropical latitudes.

year period, patterns transitioned from higher growth rates in the temperate latitudes (typically coinciding with developed countries), to higher growth rates in the tropical latitudes (typically coinciding with developing countries).

As human population has increased, so has the need for agricultural expansion. Historically, human land use changes centered on transform-

ing natural ecosystems to agriculture (Ramanakutty and Foley, 1999). Since 1700, approximately 12 million km² of forest and woodland have been cleared and 5.6 million km² of grassland and pasture have been cultivated (White et al., 2000). During these past 300 years, rapid cropland expansion occurred in Europe, North America, and Russia, while steady expansion

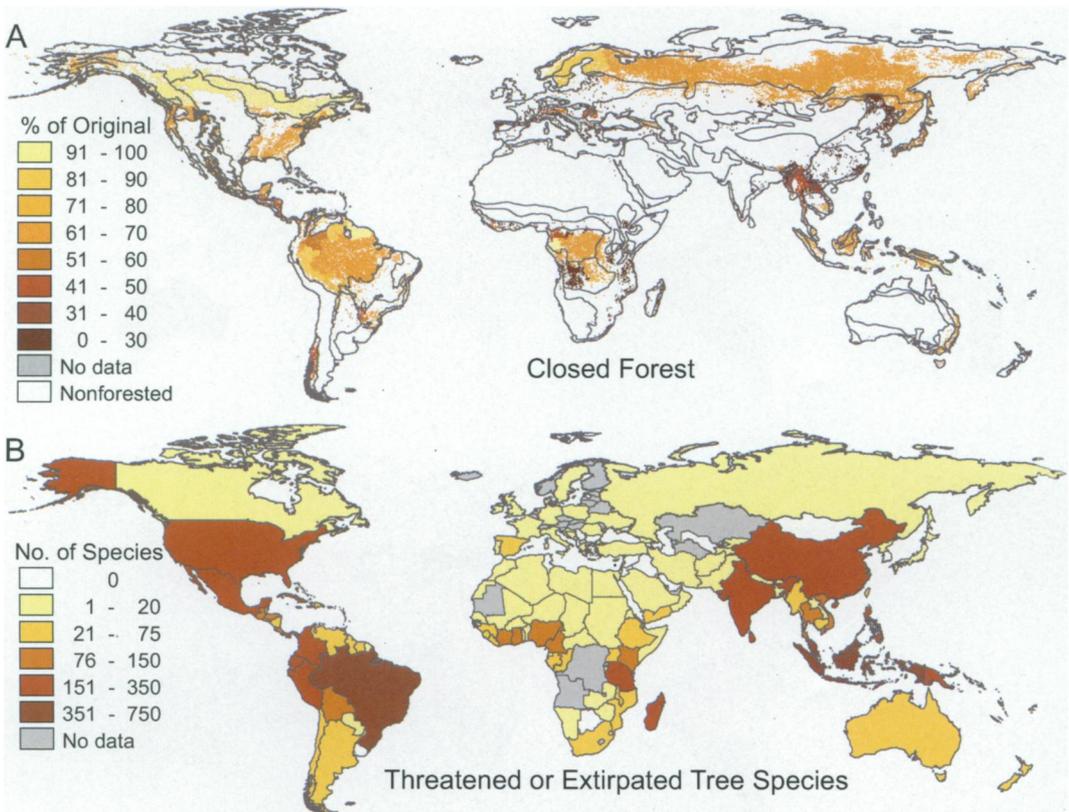


Fig. 4. (A) Percent change in the extent of closed-canopy forest cover since pre-settlement conditions (referenced to 1996). (B) Number of extirpated and threatened tree species as of the 1990s.

occurred in China. Rates of cropland expansion in Latin America, Africa, Australia, and Southeast Asia were gradual until 1850, then became exponential. More recently, North America, Europe, and Russia have stabilized or reduced their cropland area (Ramankutty and Foley, 1999), as evidenced from our map (Fig. 5A).

Although deforestation has not been limited to tropical forests, we found that much of the recent loss of natural forests has occurred in the tropical ecoregions (Fig. 4A). Malaysia had the highest number of tree species (737) estimated to be threatened or extirpated as of the 1990s (Fig. 4B), with Indonesia ranked second (426 species), and Brazil third (351 species). The United States had, by far, the highest number of threatened or extirpated species (198) among developed countries. Although data for this variable were missing for several developed countries, those that provided estimates had numbers ranging from a few species to a few dozen species.

We did not have data for mapping the rate of change in grassland cover, but we can infer loss by considering rates of cropland expansion

(Fig. 5A) in regions associated with grassland ecosystems (Fig. 1), including the Dry Steppes and Humid Steppes. There were moderate to high rates of expansion of crop area throughout the steppe ecoregions, except for in North America, where grasslands largely had already been converted long before 1961. Globally, estimates of historic grassland cover ranged from about 41–56 million km², or roughly 31–43% of the Earth's terrestrial surface (White et al., 2000).

Our map showing rates of change in fertilizer use (Fig. 5B) illustrated substantial increases in ecoregions of high amphibian species richness (Tropical Rainforests, Moist Tropical Forests, and Temperate Broadleaf Forests). In some cases (e.g., New Guinea), this increase was because the country used little or no fertilizer at the beginning of the assessment period (1961), though this was not typically the case for most countries having a diverse set of amphibians. In China, fertilizer application rates rose from 728 kg/ha in 1961 to 35,988 kg/ha in 1997, the highest application rate among all countries at that time. Brazil, another country of considerable amphibian species richness, reported an increase

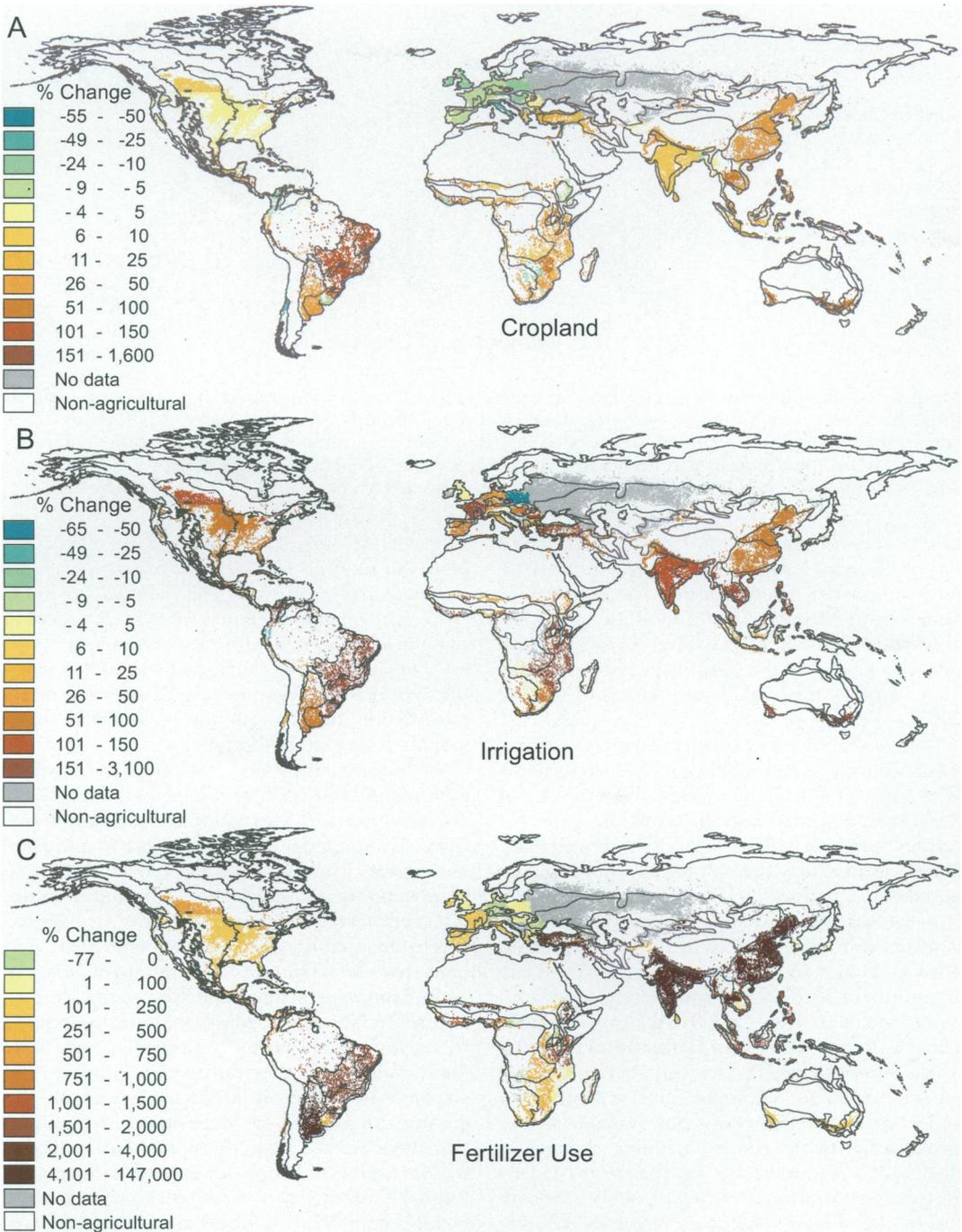


Fig. 5. (A) Changes in cropland area from 1961–1997. (B) Change in the percent of cropland that was irrigated during 1961–1997. (C) Percent change in average annual fertilizer usage during 1961–1997.

in fertilizer use from 270 kg/ha to 5,490 kg/ha for the same time interval.

While most agriculture is considered to negatively affect amphibians, impacts vary and some may be beneficial. For example, it is possible for

well-managed farm ponds to support amphibian populations in areas where wetlands are scarce (Knutson et al., 2004), a parallel of which has been noted in some Old World tropical and semi-tropical regions, where amphibian life

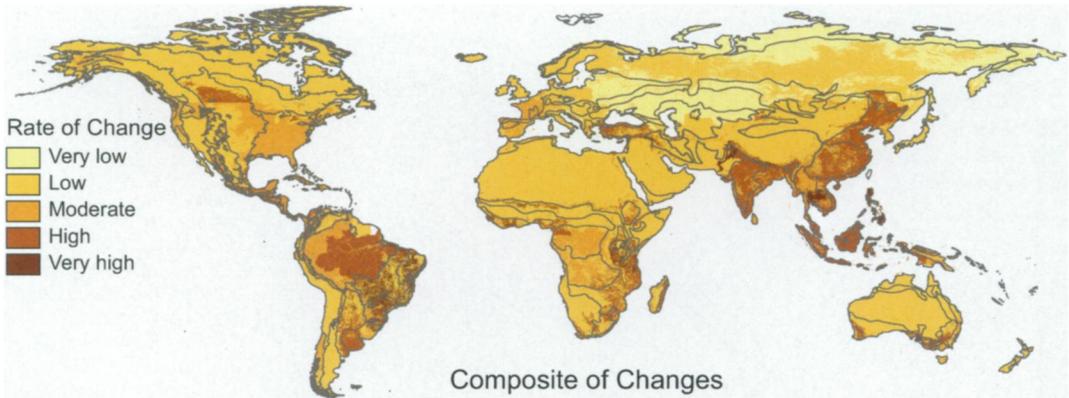


Fig. 6. Composite rates of population-, agricultural-, and forest-related change. The resulting patterns show the relative magnitude of the rates at which the landscape is being altered in ways that are likely detrimental to amphibian habitat. To generate the composite map, rates of change in the source maps (1-km resolution) were transformed to values from 1 (very low rate of change) to 5 (very high rate of change). The mean value was calculated across the source maps for each grid cell to yield this composite map.

histories are centered on rice paddies. Until recent decades, traditional Old World agriculture supported many species of amphibians. However, the introduction of modern agricultural methods, including machines and chemicals, into Asia has led to the suppression of historically high amphibian populations (Goris and Maeda, 2005).

Data availability and quality remain the greatest challenges to conducting global assessments of change. The database we used from the World Resources Institute had information gaps for various countries, time periods, and variables. Furthermore, the country-level reporting imposed artifacts associated with countries of very large geographic extents and/or discontinuous land masses. For example, in the United States, Alaska, which has undergone relatively little environmental alteration from changes in land cover and land use, “inherited” much higher rates of change because of the statistics from the conterminous United States. Still, better, or even other, choices for mapping rates of land cover and land use change were not available at the global scale. In the future, mapping changes in the Earth’s resources will be greatly assisted by global terrestrial monitoring systems. Indeed, this has been an ambition of the remote sensing community for many years. Although significant advances have been made in remote monitoring and change detection of fires and deforestation, and to a lesser extent of agriculture (Zhan et al., 2000, 2002; Roy et al., 2005), an operational, global-scale effort has not yet been implemented. Moreover, such a system would be unable to address some of the types of variables reported in the World Resources Institute database, such as

fertilizer use, loss of tree species, the distinction between natural forests and plantations, and conversion of crop types (e.g., annual to woody crops, which might then be confused with spectral signatures associated with tree plantations [“forest”] or shrub cover). So, despite the limitations of the World Resources Institute database, it offers information that would not be available from satellite sensor-derived products.

We developed a series of maps to illustrate patterns of land cover and land use change and potential overlap with amphibian distributions. There is a tendency to desire a more quantitative assessment from these data, but it would be inappropriate to apply them in that fashion, given confounded effects from the inconsistencies in the quantity and quality of land cover and land use information, the inconsistencies in amphibian representation in the survey record, and the relatively coarse mapping units dictated by country-level statistics. Regardless of these limitations, it is generally the case that the coarser the scale of landscape analysis, the greater the amount of “data noise” that can be absorbed. Accordingly, the constraints imposed by our data did not mask the information “signal” showing correspondence between areas of high amphibian richness and areas undergoing elevated rates of change.

Habitat loss, alteration, and fragmentation will continue, and most likely accelerate, well into the 21st century. It is therefore worth considering where we expect these major habitat changes to occur, and how these areas relate to habitats that support a rich diversity of amphibians. To the extent that these landscape modifications involve habitat destruction, and to the extent that

amphibian species need intact habitats to survive, we anticipate that the 21st century will bring either a wave of amphibian species extinctions, or rescues followed by captive maintenance (Mendelson et al., 2006), as exemplified by the current status of Wyoming toads (*Bufo baxteri*) in the United States (Odum and Corn, 2005).

Although the picture is not encouraging, all is not necessarily lost. Salwasser et al. (1997) pointed out evidence in the United States where it was, indeed, possible to improve environmental quality at the same time that human population continued to grow. Also, the regions that are currently undergoing high rates of change still have significant land areas that have not yet been converted. The potential exists for conservation planning that concurrently addresses human needs and ecosystem integrity in defining preserves and implementing policies that better protect the environment. Pockets of such efforts have been underway (Kremen et al., 1999; Chicchon, 2000), though it remains a challenge to optimize for both human and environmental concerns (Adams et al., 2004).

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