Ecological Complexity 20 (2014) 325–334

Contents lists available at ScienceDirect

Ecological Complexity

journal homepage: www.elsevier.com/locate/ecocom

Integrating *Homo sapiens* into ecological models: Imperatives of climate change

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ARTICLE INFO

Article history:
Received 2 December 2013
Received in revised form 1 May 2014
Accepted 12 May 2014
Available online 11 July 2014

Keywords:
Climate change
Mathematical model
Mathematical ecology
Human behaviour

ABSTRACT

In the opening lecture at a 2013 Banff International Research Station (BIRS) workshop on the impact of climate change on biological invasions and population distributions, Henri Berestycki (École des Hautes Études en Sciences Sociales) asked a crucial question: Can a species keep pace with a changing climate? "Species" in this context was generally understood to be all living things on Earth (except humans). But mounting scientific evidence suggests that it is time to pose the parallel question: Can *Homo sapiens* keep pace with a changing climate? Furthermore, should we merely "keep pace", or should we strive to get ahead and then do our utmost to stop any further climate change?

In this paper we document the very real potential for climate change to have devastating consequences before the end of this century. The urgency of the situation calls for concerted action by anyone who understands the problem, and mathematical ecologists are uniquely trained to contribute to such efforts. We ask modellers to deliberately incorporate the species *H. sapiens* into their modelling work, and offer suggestions as to how this might be done. Ultimately modellers must seek ways to provide guidance to citizens and policy-makers as we all wrestle with the most important existential threat of our time.

1. Introduction

The magnitude and pace of climate change have simultaneously reached a point where new modelling approaches are needed (Gilman et al., 2010; Warren, 2011). The 2013 BIRS workshop entitled "Impact of climate change on biological invasions and population distributions" (Berestycki et al., 2013) which inspired this special issue of Ecological Complexity, focussed on ecological models incorporating climate change. A common approach in nearly all of the workshop models was to assume particular changes in one or more climatic variables (temperature, climate variability, precipitation, etc.), and then explore the consequence of this change to (1) shifts in species range boundaries, (2) dynamics of invasive species, (3) multispecies interactions, and/or (4) shifting patterns of vegetation (Berestycki et al., 2013). The excellent work presented at the workshop documented a host of consequences for species persistence, biodiversity, genetic variability, etc. We were struck, however, by the relative scarcity of models incorporating any feedback to the human-related mechanisms of climate change. This omission is common in the ecological modelling literature: While there is an extensive and valuable body of work looking at the current and future impacts of climate change on a host of organisms, few models in ecology include the primary agent of all this climate trouble: *Homo sapiens* (Liu et al., 2007). In this paper, we argue that there is a strong need to include humans and human behaviour in ecological models addressing climate change.

There is a long history of mathematical models in ecology that treat humans as separate, possibly rooted in the notion, conscious or unconscious, that humans are somehow different or above the workings of ecological systems. Indeed, Judeo-Christian scripture puts us on this pedestal: "And God said, Let us make man in our image, after our likeness: and let them have dominion over the fish of the sea, and over the fowl of the air, and over the cattle, and over all the earth, and over every creeping thing that creepeth upon the earth."[1] The notion stuck in the western world, at least for awhile: We humans are different – we have dominion, and that may have never been so evident as it is today.

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[1] Genesis 1:26, King James version.

http://dx.doi.org/10.1016/j.ecocom.2014.05.008

An additional reason to leave humans out of models incorporating climate change is the pervasive notion that there is not much that we can do about global warming. For example, a 2006 survey by the Pew Center found that 22% of Americans believed that there is nothing that humans can do to reduce the effects of global warming (Pew Research Center, 2006). The absence of human behaviour from ecological models suggests that many mathematical ecologists simply accept that climate change is happening, and seek to determine the consequences to ecological systems. This approach is fine as long as the anticipated change is not too drastic, and simply adapting to the altered climate is sufficient. Unfortunately, we have reached a point where catastrophic bifurcations are entirely possible (Boulton et al., 2013; Budzianowski, 2013; Di Paola et al., 2012; Ashwin et al., 2012; Kwadijk et al., 2010). A recent report (Schwartz and Randall, 2003; Shearer, 2005) examined threats to National U.S. Security posed by climate change through disruptions of food, water, or fuel: "[o]cean, land, and atmosphere scientists at some of the world's most prestigious organizations have uncovered new evidence over the past decade suggesting that the plausibility of severe and rapid climate change is higher than most of the scientific community and perhaps all of the political community is prepared for." Consider the consequences of having supply centres of essential commodities such as oil taken out by severe storms [already increasing in magnitude and geographic extent (Karl et al., 2009)], food supplies severely reduced or eliminated through the loss of pollinators [already experiencing significant decline (Potts et al., 2010; Vanbergen et al., 2013)] or through trophic mismatch (Harrington et al., 1999), and drastic reductions in the availability of clean water through disruption of the hydrologic cycle (Sachs, 2009). The trajectory of anthropogenic activity is predicted to lead to severe changes as soon as the year 2100, when children and grandchildren born today are only in their 80s (Mora et al., 2013; IPCC, 2013a). If we are lucky, the changes will be slow enough for humans to adapt gracefully to them, but it is not at all clear that our luck will hold. As mathematicians know, bifurcations can be dramatic. It is therefore not enough to simply accept that climate change will happen: We must do something about it.

It is important that we establish at this point that it is indeed human activity that is changing the Earth's climate. The evidence for this view continues to mount, and the latest report from the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013a) states with high confidence that global warming is due largely to anthropogenic forcing. Given that it is anthropogenic activity that is almost surely the chief cause of global warming, it is clear that we humans can no longer be considered "separate" from the natural systems we inhabit, at least when it comes to climate change. Since humans are causing the climate problem, humans also hold the key to solving it.

In this paper, we present as a call to arms a brief primer on climate change and the implications thereof (Section 2), and then argue that there is a pressing need for mathematicians to engage in studies that consider the human factor as a dynamic element in our models (Section 3), and give some illustrative examples. Finally, we argue that we mathematical biologists need to speak broadly about our results (Section 4) so as to raise awareness of the situation with as many people as possible and, hopefully, inspire effective action. If we are fortunate, together with our neighbours we will influence those with the power to change our current and potentially disastrous trajectory.

2. Climate change as crisis

We begin by assembling here an easily communicated collection of some of the most accessible research regarding climate change. For many people, the issue remains a threat too large or too distant to really comprehend at a personal level. The assertion that an average increase of 2 °C is disastrous is difficult to reconcile with personal experience of annual and daily temperature swings considerably larger than 2 °C. The material gathered here helps to personify the problem and put climate change into perspective. Our goals are to clarify the urgency of the situation to you, the reader, and to arm you with information that can be used in discussions with friends and colleagues.

Our assertions of human responsibility for climate change are justified by the findings detailed in the 2013 fifth assessment report (AR5) of the IPCC[2]. One of the highly publicized findings is that, with 95% certainty, humans are the principal drivers of the rapid global warming we have experienced over the period since the beginnings of the industrial revolution, and that the culprits are the greenhouse gases that we have been emitting. Some people have puzzled over the use of "95%" certainty (up from 90% in the 2007 IPCC report). A recent AP news report puts that figure into better perspective: "Top scientists from a variety of fields say they are about as certain that global warming is a real, man-made threat as they are that cigarettes kill... They say they are more certain about climate change than they are that vitamins make you healthy or that dioxin in Superfund sites is dangerous" (Borenstein, 2014).

The inescapable scientific conclusion is that we humans are manipulating the composition of the atmosphere, using the skies as an enormous carbon dumping ground, and are thus altering our climate. There has been to this point no direct cost for doing so [the cost has been externalized (Nordhaus, 2013), "represent[ing] the biggest market failure the world has seen" (Stern, 2008)], and so this practice has continued up to the present in a global demonstration of the Tragedy of the Commons (Hardin, 1968).

Given that humans are indeed responsible for global warming, we now continue our story to its logical conclusion. The rest of the story is based on three critical information sources for climate change (one data set and two organizations): The Keeling data, the United States' National Academy of Sciences (NAS), and the Intergovernmental Panel on Climate Change. That the authority of these voices is being so widely disregarded or, even worse, dismissed is something of a mystery; that their tale is not at the forefront of discussions throughout the halls of academia is a cause for acute dismay. We acknowledge and thank those people giving impassioned and eloquent deliveries of this story (Annan, 2013; Vidal, 2012), but the message is not being taken seriously, by and large, as evidenced by the lack of concerted international action.

The story begins with the Keeling data (NOAA, 2014), called the most important environmental data set taken in the 20th century (Kennel and Keeling, 2011). Charles David Keeling demonstrated the rapid and inexorable increase in CO_2 that has occurred with steadily increasing industrialization worldwide (Fig. 1). In spite of the Kyoto Protocol (1997), a treaty with the stated purpose of reducing greenhouse gas emissions, the planet has shown no evidence of a slow-down in CO_2 pollution. In fact, it appears from the graph in Fig. 1 that the trend is actually accelerating (an acceleration attested to as well by the World Meteorological Organization in their 2013 Greenhouse Gas Bulletin (World Meteorological Organization, 2013)).

The increasing levels of CO_2 in the atmosphere are accompanied by increasing global temperatures (Fig. 2). Since the industrial revolution, global mean temperatures have increased by 0.8 °C, and current trends indicate that we could see an increase of anywhere between 1.8 and 4 °C by the end of the 21st century (Working Group I, 2007). On a daily basis however, humans regularly experience daily temperature swings of anywhere between 5 and 15 °C. Why, then, is an increase in global mean

[2] Working Group I's report on the physical state of climate (IPCC, 2013a).