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# Extinction Risk, Ecological Stress and Climate Change: How Species Respond to Changes in Global Biodiversity?

Sidharta Chatterjee<sup>1</sup>

## Abstract

This paper studies the impact of climate change and habitat loss on extinction threshold of species. When global biodiversity is gradually being altered by human activities, species respond differently to such alterations in response to habitat destruction and habitation fragmentation. This alteration of global biodiversity is accounted for to be the effect of climate change which is anthropogenic in origin, as we commonly call it global warming. This global warming is not only bringing about alterations in climatic patterns, but such drastic changes are reflected in species behaviour as well, wherein, some species are either adapting to such changes, or becoming extinct. The study was done by modelling such a system which would impose stress effect on the species and determine their extinction or survival thresholds. The results indicate that the model is effectual, and it is possible, with data availability, to apply the model to compute changes in extinction thresholds or compute the effects what climate change have on such species.

**Keywords:** Biodiversity, habitat loss, climate change, extinction threshold, adaptive capacity.

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## 1. Introduction

Human beings, among other extant species, are considered to be the best resilient species of all to have evolved, withstood and survived the cycles of ecological variations through the ages. This evolutionary survival by adaptation, or adaptive evolution [Manning et. al., 2012] per se, is not just limited to humans, but to all other species who constantly adapts to the different challenges that the nature presents [Hoffmann & Sgrò, 2011]. The nature of adaptive survival of each species provides the general characteristics about the mechanisms underlying species-specific ecological adaptations in nature. This nature of ecological adaption has been enumerated by various studies which have investigated the molecular basis of adaptive evolution in several species. Compared to other species', the adaptive capacity and resilience of human beings [Holling 1973], Carpenter & Brock, 2008] are nevertheless, remarkable, as well as our colonization abilities. Not all and every species enjoy such an advantage, and this pertains to species-specific vulnerability to ecological changes [Preston & Stafford-Smith, 2009]. Since, it is the human beings that on being at the top of the intelligence chain having incessantly reshaping their direct and indirect ecological surroundings which have however, put many other subordinate species less intelligent than us, at risk of extinction. In other words, anthropogenic activities have made other species sensitive to changes in climate and habitat vulnerable to extinction [Parry et. al., 2007]. In such course of activities, the global biodiversity is gradually being tampered with, habitats getting fragmented [Fahrig, 2003], and the natural land cover (i.e., rainforests) reduced [Vitousek, 1994], Vitousek et. al., 1997]. Measuring the ecological impact of habitat loss coupled with other environmental stress factors (including climate change effects) on the surviving species that survive in habitat remnants [Ewers & Didham, 2006] poses as one of the most challenging issues

confronting ecologists and conservationists. At one hand, surviving species in a fragmented habitat continue their struggle for existence, while on the other hand, by course of such actions, if they adapt successfully, they learn how to survive. Hence, it appears now that there is a constant tussle going on between extinction and survival thresholds of species under ecological stress that which is being continuously adjusted as far as species vulnerability to extinction and adaptive capacity for survival of these species concerns about. More than that, it is now apparent that the global biodiversity is being relentlessly altered by human interference. And this interference is perhaps inducing climate change [Watson et. al., 1998] which is predisposing several species toward extinction by causing severe alterations in their biotope. Some species are so sensitive to the effects of climate change that even a high rate of reproductive capability coupled with higher degrees of adaptive capacity and colonization rate cannot prevent them from going bust into extinction. Already, there are enough evidences of *phenological changes* affecting the duration of biological events among several different species due to impact of climate change on biodiversity [Willis & Bhagwat, 2009]. Particularly, Parmesan & Yohe [2003] have analysed the long-term large-scale multi-species data on climate change effects affecting biodiversity. Also, the impact of climate change on biodiversity have been documented in much detail by Pearson & Dawson [2003] who have used spatial scale models to simulate species' bioclimatic envelope. The matter as of how this global biodiversity is altered in the face of climate change [Hansen et. al., 2001], and how such alteration affects a species' bioclimatic envelope, however, remains a much sought after topic for further investigation when the accompanying changes affecting biota are taken into consideration. Furthermore, how such accompanying changes in biodiversity affect a species' survival threshold could be an interesting avenue for further research. In fact, J.M.J Travis [2003] discusses about these aspects related to a toxic cocktail brought about by the combined effects of climate change and habitat destruction on global biodiversity. The author points out that the interaction between climate change and habitat fragmentation can not only be disastrous, but which could lead to species extinction, particularly for those habitat specialists who are poor colonizers. This research points in that line of analysis although taking a different path using a functional model to generate habitat patches in order to delineate the range of risk threshold (range-risk threshold) [Walker & Meyers, 2004] for a given species, something analogous but new-fangled to the spatial scale modelling (patch occupancy models) approach which Travis [2003], Bascompte et. al. [1996], or metapopulation dynamics which Hanski [1999] have adopted in analysing the extinction thresholds of species in response to climate change and habitat loss. This study, furthermore, in keeping with the contemporary line of thinking on the subject matter, attempts to model habitat loss coupled with climate change and examine how such changes induce stress on different species. That is, how climate change coupled with habitat loss induce stress on the species' survival? The study hence contributes by extending an old interpretation in a new flavour; that is, why species with poor colonizing ability are prone to mass extinction when their habitat becomes fragmented? More than that, the research investigates explicitly how climate change induced by global warming affects habitat threshold.

## 2. Global Warming, Climate Change & Ecological Destruction:

Scientific evidences of climate change affecting the natural habitat—biotope, is abounding, which points to four main affirmations;

- a) Climate change brings about ecological instability [Harris et. al., 2006],
- b) Climate change coupled with global warming is assumed to be anthropogenic in origin [Watson et. al., 1998], IPCC (Edited by Gitay et.al, 2002), Chatterjee [2013], or, in other way, climate change is on account of global warming which is anthropogenic in origin.
- c) Anthropogenic activities cause loss of biodiversity and habitat fragmentation (clearance), and
- d) The combined effect of all of the above, causes a “reduction” in habitat availability inducing stress on those species.

The above four facades points to at least one important element— which is, these are *stress inducing factors* and that the species are under “stress”, and understanding the nature of such stress induced by climate change on

species-at-risk possess yet another challenge. The challenge is—how to minimize the stress and limit *habitat loss* as well as to reduce ecological destruction [Harris et. al., 2006] which endangers several species and puts others at the path of extinction. It has been predicted that global climate changes can cause species extinction in the next 100 years [Cahill et. al., 2012], and by the turn of this century, it is presupposed that much of the remaining rainforests and natural habitats would be consumed by the forces of human needs. Hence, it is equally germane to model, investigate and understand species' response to such altered biodiversity compounded by habitat loss—much of which has been on account of climate change, and hence, formulate strategic resolutions to conserve the remaining biodiversity [Chatterjee, 2013]. Since most of these processes points to human interventions, as far as scientific consensus on the subject matter points to [Peters et. al., 2013], [Meinshausen et. al., 2009]. Nonetheless, this matter is significantly non-trivial; since, it is linked to the ultimate survival or extinction of several species in question under stress induced either by climate change, habitat loss or both. However, even if there are definable non-climatic and biological causes of species extinction [Sodhi et. al., 2009], the most fervent of the causes nevertheless are implicated to non-biological or ecological grounds—induced primarily by anthropogenic actions contributing toward habitat destruction and global warming—a cause itself having its origin from human activities. The overall effects relates to the nature of adaptive survival of the species in distress; i.e., of about how they respond to such changes in their habitat and subsequently, it is motivating to offer explanations based on the scientific findings about how different species respond differentially in their own way to climate change. That is, whether if such species are able to endure such alterations in their habitat, and for how long or if they gradually become extinct as their habitat availability (destruction) reaches a critical threshold below which, they do not survive. Several studies have pointed out about species-specific threshold in habitat availability using patch occupancy models [Dytham, 1994] investigating how climate change affect the habitat threshold and ultimately contribute to species extinction.

### 3. Habitat Loss, Adaptive Capacity & Colonization Ability of Species:

*Habitat* is referred to as the home territory within which species inhabit. A habitat is characterised by favourable environment that which defines a “biotope”—an ecological community uniform in environmental conditions, i.e., climatic, edaphic and biotic factors and in its population of plants and animals. Habitat loss, habitat fragmentation [Fahrig, 2003], [1997] and habitat destruction occurs when the total amount of habitable patch for a particular species which inhabit in such a biotope is reduced by means of human actions; by way of deforestation [Molchanov, 1970], clearing of land for agriculture, urban encroachment, mechanized erosion of landmass, forest floor clearing for highways and industries, and alteration by the effect of climate change on account of anthropogenic activities [Vitousek 1994], [Anderson et. al., (GSPP 964, 1976)]. Natural Habitats also become unsuitable for a given species due to forest fires, seasonal variations in the pattern of rainfall (severe drought), territorial spillage from industrial pollutants, contamination of natural water reservoirs and land cover usage [IPCC, 2002]. The consequences of such habitat damage can be both implicit and explicit; the ultimate survival, migration or extinction of a given species depends on how species' responds to different degrees of habitat loss, and how they adapt to such changes in their home territory or recolonize to other habitat patches, etc. Several studies have analysed these aspects using patch occupancy model [Bascompte et. al., 1996]. Modelling habitat loss hence mandates understanding the habitat characteristics of a given species, as for example, of marine corals. Indeed there is a particular habitat threshold below which a species rapidly become extinct, irrespective of its adaptive capacity and colonization rate. This is highly visible in marine corals which starts to bleach (Coral bleaching) once the surface water temperature of oceans and seas increases [Keller et. al., 2009]. Although this is not in fact an example of habitat loss, but an effect of increasing temperature due to ocean warming accountable to climate change, owing much to global warming. Environmental characteristics also reduce a species' ability to persist in a fragmented habitat. However, different species respond differentially to habitat loss and climate change [Travis, 2003] while there are other biological factors (i.e., genetic susceptibility, resilience etc.) that influence a species' ability to withstand climate change. Nevertheless, anthropogenic activity-induced changes presents as the single-most extinction risk for many biotic species [Araujo et. al., 2003], including themselves. Some of the species most prone to extinction during climate change and due to habitat loss can be found in [Foden et. al., 2008] from which the reader may wish to draw a general notion about the necessity to preserve and conserve the ecological balance of the remaining ecosystem. Several other studies have highlighted the impact of

climate change on species survival and range retractions [Thomas et. al., 2006] wherein species face extinction on account of severe ecological stress.

#### 4. The Model: Aims & Scopes

The model adopted in this research is aimed toward understanding how climate change and habitat loss have stress inducing effect on species. Furthermore, this model attempts to simulate the impact of climate change which predispose species toward extinction using a simple OLS model of the function of species survival on different independent variables acting in concert. The present study revolves around computing and identifying extinction thresholds in response to climate change and habitat loss [Hill & Caswell, 1999], and furthermore, to observe how global warming could augment these adverse processes. Another goal of this investigation is aimed toward prediction of extinction risk underneath climatic transformation, a study performed earlier by David Keith and others [See Keith et. al., 2008]. Nevertheless, the present study includes two-factor model equation with several variables whose parameters are defined as follows; variables of climate change, global warming, habitat loss, adaptive capacity and colonization ability. The model assumes a fundamentally different approach from other contemporary studies in that, I do not adopt a patch occupancy model to study the effect in the present case, but propose two functional equations which can be statistically computed to model the overall impact of the variables on species survival. The most crucial factor in this investigation is, to identify the changing patterns of habitat-at-extinction-risk threshold computed from the derived values of extinction threshold(s) using the model which could as well be delineated by shifting patch regimes (using palettes).

##### a. Methodology

This study includes a multivariate functional model. The first equation modelled is to assume the behaviour of the system which is to be demonstrated such that it can be tested applying OLS regression or plotted following differentiation on the response variables—

$$Y(S') = a_0 - (x - n)\alpha_1 - x^2(1 - n)\alpha_2 - x^3(1 + n)\beta_1 + (1 + n)x^4\beta_2 + x^5\beta_3 \quad \text{eq. 1}$$

Where,  $Y$  is defined as the function of survival ( $S'$ ) of the species in question which studies the effect of the variables on the right hand side of the equation. The values  $\{x \rightarrow x^n\}$  are defined by the operator variables  $\{a_0, \alpha_n \rightarrow \beta_n\}$ , whereas  $a_0$  is the 'constant' element of observation in a series attributed as  $\kappa$ . The definitions of the variables are given as data regarding;

$\alpha_1 x$  = effect of climate change measured in terms of atmospheric CO<sub>2</sub>, in terms of ppm,

$\alpha_2 x^2$  = the variable degree of measure of global warming with respect to  $\alpha_1 x$ , (change in global Mean Temp-( $\zeta$ ))

$\beta_1 x^3$  = amount of habitat loss measured in terms of the change total habitable area  $\Delta x = (\tau - \theta)$ ,

$\beta_2 x^4$  = adaptive capacity of a species, derived from the ratio of reproductive rate ( $\sigma$ )/extinction rate ( $\eta$ ), and

$\beta_3 x^5$  = colonization ability of a species, derived from area under new colony of habitat patches occupied ( $\vartheta$ ).

The second equation is a variation of the hyperelliptic generalization of Mordell's equation [Beukers, 2011] given as;

$$y^2 = x_n + a_1 x^{n-1} + \dots a_{n-1} x + a_n \quad \text{eq.2}$$

The second equation, derived as a generalization of Mordell's equation is adapted to slight modification to accommodate the variables defined by their respective parameters to define the system and is bounded. The equation be defined as;

$$Y(t') = a_0 - \alpha_1 x^{d-1} - \alpha_2 x^{d-1} - \beta_1 x^{d-1} + \beta_2 x^{d-1} + \beta_3 x^{d-1} \quad \text{eq.3}$$

Which describes the system explaining the effects of each of the individual variables (where  $t = \text{extinction threshold}$ ) and takes the finite set of possibilities that may exist when the parameters describing the operators are manipulated. The equation takes in the form of definitions given as above in equation 1 and where, the exponent  $(d - 1)$  explicates the number of solutions bounded by  $d = \{k\}$ . The difference between the first equation no. 1 and equation no. 3 is that the first representation is unbounded whilst the second one is bounded. This follows from the extreme value boundedness theorem which states that the functional value has no maximum, contrary to the first equation. Now, by reducing the first equation no. 1, we derive (steps omitted);

$$a_0 - (-n + x)\alpha_1 - (1 - n)x^2\alpha_2 - (1 + n)x^3\beta_1 + (1 + n)x^4\beta_2 + x^5\beta_3 \quad \text{eq. 4}$$

By simplifying equation no. 4, we derive,

$$a_0 + (n - x)\alpha_1 + x^2((-1 + n)\alpha_2 + x(-(1 + n)\beta_1 + x((1 + n)\beta_2 + x\beta_3))) \quad \text{eq.5}$$

Applying the rule of partial differentiation, let us derive by partial differentiation on  $x$ ,

$$\partial_x \left( a_0 + (n - x)\alpha_1 + x^2 \left( (-1 + n)\alpha_2 + x \left( -(1 + n)\beta_1 + x((1 + n)\beta_2 + x\beta_3) \right) \right) \right)$$

$$-\alpha_1 + x^2((-1 - n)\beta_1 + x((1 + n)\beta_2 + x\beta_3)) + x((1 + n)\beta_2 + 2x\beta_3)) + 2x((-1 + n)\alpha_2 + x((-1 - n)\beta_1 + x((1 + n)\beta_2 + x\beta_3))) \quad \text{eq.6}$$

Now, again by reducing eq. 6, we derive the solution to be manipulated,

$$-\alpha_1 + x(2(-1 + n)\alpha_2 + x(-3(1 + n)\beta_1 + x(4(1 + n)\beta_2 + 5x\beta_3))) \quad \text{eq.7.}$$

By plotting equation eq. 7, we generate a response defining the curve functions which would likely define the impact of the independent variables on  $Y(S)$ . At equilibrium point within a biotope with no climate change and global warming taking place  $\{0, 0\}$ ,  $\{0, 0\}$ , and with minimal degree of biodiversity loss  $\{0, 0.1\}$ ,  $\{0.0, 0.05\}$  and furthermore the species exhibiting a variable but modest range of adaptive capacity and colonization ability given by  $\{0, 0.5\}$ ,  $\{0, 1.2\}$ , there remain no definite threat to the survival of the species (See Fig. 1), but such an ideal equilibrium condition is seldom achieved but only under controlled settings.

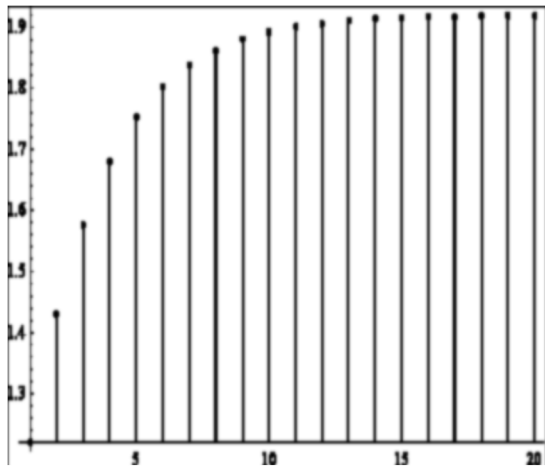


Fig. 1

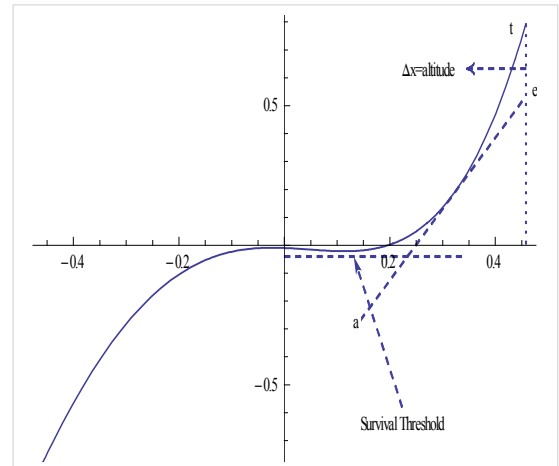
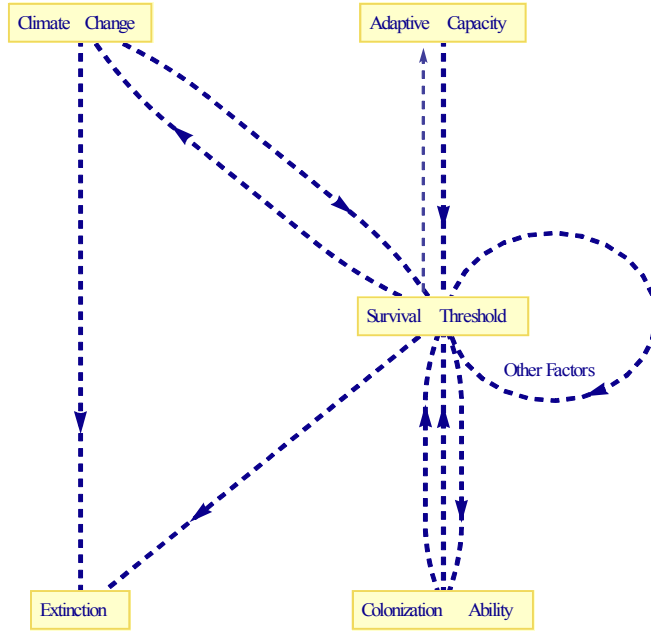


Fig. 2

The model (as depicted in Fig. 3 below) delineates much about the adaptive struggle for survival under conditions defined by some unfavourable degree of environmental resistance and ecological stress to which the species are exposed to, maintaining a high degree of adaptive capacity and a still higher degree of colonization

rate. This is evident from the figure 2, which is apparent given a closer inspection. The model depicts that the survival threshold is marginally restricted for some species that cannot tolerate even little alterations in climate change, yet, can resist substantial loss of habitat.



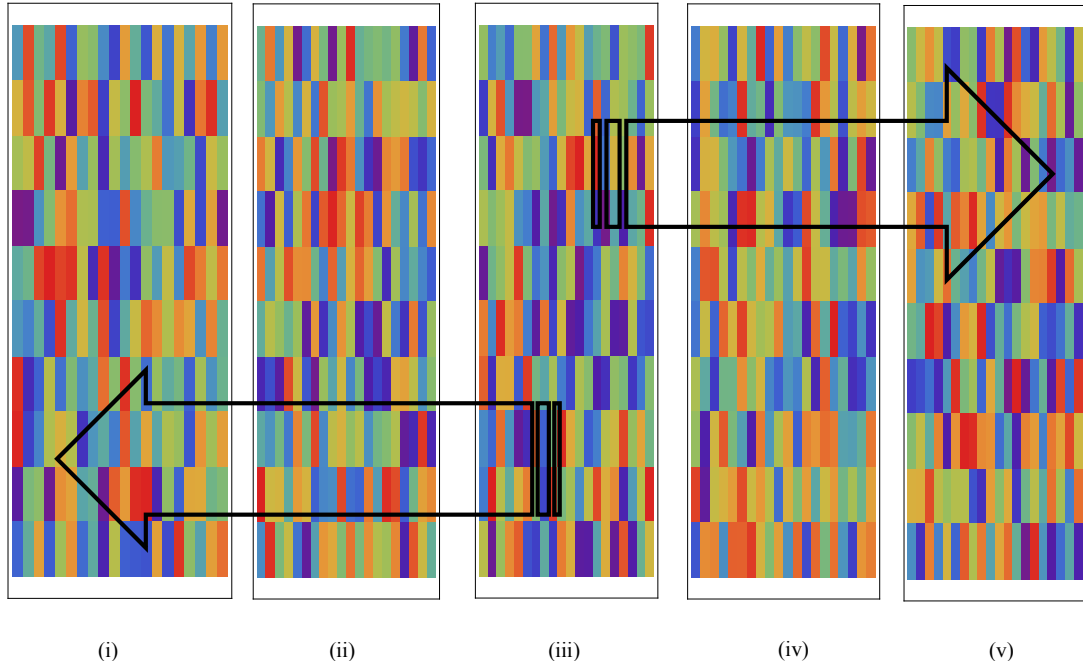
**Fig. 3** The tree diagram of feedback loops presenting the model which affect a species' survival rate. Note: all of the above variables, i.e., climate change, adaptive capacity, colonization rate (and other factors) affect survival threshold in feed-forward and feedback modes. Also, the above factors dynamically impact the extinction of a species, which is an irreversible process, characterized by mortality rates exceeding reproduction rate of a given species at a given time.

Several questions may likely prop up; how can species adapt under unfavourable environmental conditions and sustain a chance of survival? How their survival threshold is affected by a given condition of alteration in habitat, climate change and biodiversity loss? How global warming exacerbates the climate change process and predisposes them toward rapid extinction? Given from Fig. 2 plotted from equation 7, it is evident that the chances of survival of a species decreases substantially more so when the “climatic conditions” become increasingly unfavourable more than what the loss of biodiversity can contribute to its overall survival. In such a scenario, the species must maintain a very high rate of reproductive capacity  $\{n > 1.5 \leq 2.0\}$  to survive adverse environmental conditions. However even though, under similar given conditions, when the rate of loss of biodiversity tends to increase exponentially, the species moves more rapidly towards extinction, but less than that contributed by alteration in climate. Now, following the tangent  $(x_a \rightarrow x_e)$  where  $\Delta x = \text{altitude}$ , is given by  $t \rightarrow e$  drawn in Fig. 2 on the curve function, we can follow the downward slope of the curve with the height falling from  $t \rightarrow e$  as there occur gradual loss of biodiversity. However, the threshold for survival seems to be apparently too low  $\{\text{where } Y(S) = 0.023\}$  for a given species and which is affected by further loss in biodiversity and increase in global warming which would explicitly alter climate and hence, implicitly induce further stress on the species'. This value of  $Y(S)$  is derived using the Mean Value Theorem (MVT) given by the formula [Gillett, 1981] from where we could employ the derived coordinates to derive habitat patches and patch threshold.

$$m = f(b) - f(a)/b - a \quad \text{eq. 8}$$

$$f'(c) = (f(0.002) - f(-0.01))/(0.16 - 0.004) = 0.076$$





**Fig. 4** Legends (i)-(v): Schematic outline of habitat patches including the “range” of species extinction risk threshold created from the coordinates of equation 8. Note the different kinds of habitat patches generated as the species hovers around and near its extinction threshold. The “optimum” survival threshold of a species is denoted by patch (iii) while the minimum threshold for survival is indicated by patch (i). Each coloured box indicates a different habitat. The arrowheads indicate to-and-fro outbound range of threshold of a species at risk which deviates from the optimum give as (0.076) in Legend (iii). For more details, refer to the models used by Bascompte & Sole (1997), and Travis (2003).

Where,  $m = f'(c)$ ,  $c$  is somewhere between  $a$  and  $b$  on the curve  $a \rightarrow t$ . The traced coordinates insofar are derived from the chord joining the base of the curve ( $a, f(a)$  and  $b, f(b)$ ). Tracing this value of  $X$  on the curve function yields the value of  $Y$  as a threshold lower limit value of function ‘ $c$ ’ determined to be 0.023 given as a derived value function of  $Y(S)$ . Below this threshold value, the species’ fails to survive and rapidly becomes extinct. As far as the model is concerned, I do not include many other variables as factors of impact like forage availability, impact of endemic diseases et cetera which is beyond the scope of the present model. In such dialect, the above system is a more generalization of the actual scenario within which a species inhabit. I shall discuss the implications of these in the following results section. Now, another simulation of the model could be performed by adopting equation no. 2 which fittingly describes the system of species living under stress.

Substituting the operator variables in equation 2,

$$Y(x) = a_0 - \alpha_1 x^{d-1} - \alpha_2 x^{d-1} - \beta_1 x^{d-1} + \beta_2 x^{d-1} + \beta_3 x^{d-1}$$

Let us convert this into a simple generalized formula for the solution given as to measure the stress level induced on species’;

$$a_0 - x^{-1+d}\hat{I}_1 - x^{-1+d}\hat{I}_2 - x^{-1+d}\hat{I}_1^2 + x^{-1+d}\hat{I}_2^2 + x^{-1+d}\hat{I}_3^2 \quad \text{eq. 9}$$

Whereas, by plotting for  $Y(S)$  both eq. 2 & 8, we derive graphs as shown in the appendix (P.S.).

## 5. Results & Discussion:

The simulation of the model describing the fingerprint of habitat loss [Parmesan & Yohe, 2003] coupled with climate change having impact on the survival of a species’ unfolds several interesting facts about how species might respond to a myriad of changes in its environment. It is evident from the model that habitat specialists who



are poor colonizers are sensitive to any minute alterations in their home environment, including any slight change in climate. On the other hand, to compensate for habitat loss, a species must have a higher adaptive capacity and colonization ability in order to survive or migrate to favourable regions when its environment gets fragmented. However, a higher degree of the above two factors still fails to compensate for a sustained alteration in climate, which threatens species survival. Beyond habitat loss, the single most factor of importance is the effect of climate change, which may be further exacerbated by global warming which aggravates the level of stress that furthermore augments species extinction. Additionally, habitat regeneration though can compensate for some degree of changes in other biogenic factors, species' nevertheless sustain up to a certain threshold below which its survival is threatened. Another significance of this model is that, it helps to compute the extinction threshold using Mean Value Theorem on the curve function for any given species on condition if such data about other autonomous variables are computed alongside the given parameters. Seen other way, climate change may have a direct effect on species-specific habitat threshold. Another finding which may be significantly elicited is that, if the adaptive capacity of a species is affected, and which may be due to other pathogenic, biological or genetic factors, that species moves toward extinction more rapidly than the one which maintains a high degree of colonization rate and optimum adaptive capability. Understanding the combined effects of climate change and habitat loss on species is important since, these are the two primary contributing factors behind species extinction. Further research on the these aspects of how a species is sensitized by climatic shifts, or affected by the combined influence of the above factors including habitat loss and lower adaptive capacity would, perhaps likely shed some more light on the science of adaptive survival.

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