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Insights into the impacts of three current environmental problems on Amphibians

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ABSTRACT

Global warming, light pollution and noise are common human-induced environmental problems that are escalating at a high rate. Their consequences on wildlife have mostly been overlooked, with the exception of a few species with respect to climate change. The problems often occur simultaneously and exert their negative effects together at the same time. In other words, their impacts are combined. Studies have never focused on more than one problem, and so, such combined effects have never been understood properly. The review addresses this lacuna in the case of amphibians, which are a highly vulnerable group. It divides the overall impacts of the problems into seven categories (behaviour, health, movement, distribution, phenology, development and reproductive success) and then assesses their combined impact through statistical analyses. It revealed that amphibian calling is the most vulnerable aspect to the combined impacts. This could provide important input for conservation of amphibians.

KEYWORDS

Amphibians, light, global warming, noise

INTRODUCTION

Amphibians play critical roles in food webs, and often link terrestrial and aquatic ecosystems (Bickford et al. 2010). They also affect ecosystem structure through soil burrowing and aquatic bioturbation, and provide ecosystem functions such as decomposition and nutrient cycling through waste excretion (Hocking & Babbitt 2014). However, these organisms are threatened by several factors in the present times, and are declining at a faster rate than birds and mammals (Stuart et al. 2004; Beebee & Griffiths 2005). In fact, the global amphibian decline is a formidable environmental problem of the late 20th century (Daszak et al. 1999). Amphibians often have complex life histories; their permeable skin fulfils several physiological functions and is sensitive to the micro climatic conditions as well as to pollutants. Because of these traits, amphibians are more sensitive to human related environmental changes than other vertebrates, currently being in global decline (Kerby 2010).

Amphibians are good model organisms to assess the potential impact of humans on biodiversity because of their trophic importance, environmental sensitivity, research tractability and impending extinction (Hopkins 2007). Therefore, the present review has been undertaken to understand the combined effects of three environmental problems (noise, light pollution and global warming) on amphibians.

The review is the first-hand approach to make a combined valuation of the overall impact of the three issues on amphibians. It understands the respective negative impacts of the three issues on amphibians, and then divides the overall impacts into seven categories (behaviour, health, movement, distribution, phenology, development and reproductive success). Below I will provide a short overview of the relevance of the three issues for biodiversity.

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Noise

Noise is an environmental force that alters the behaviour and distribution of many wild vertebrates (Francis et al. 2012), and exerts selection pressure on acoustic signals (Ryan & Brenowitz 1985). It has the potential to severely affect wildlife (Brumm 2010). In fact, human induced acoustic environment is a selective force that alters communication patterns of many vocalizing anurans (Roca 2016). This is because a decrease in acoustic habitat due to anthropogenic noise acts as an environmental stressor on sensitive animal groups (Nelson et al. 2017).

During the recent past, urbanization and development in the transport sector have increased the levels of noise (Fuller et al. 2007). More powerful sources of noise, greater geographical spread and mobility of noise sources, and a greater proportion of the day being exposed are important reasons for this (Berglund & Lindvall 1995). Its intensity has also been increasing in many previously intensively developed regions (Berglund & Lindvall 1995). Noise is expected to increase in the coming decades, but few studies have investigated the effects of anthropogenic noise on anurans (Caorsi et al. 2017).

Light

The rapid global increase in artificial lighting has transformed nightscapes both in quantity and quality (Hölker et al. 2010). Such a change in the nocturnal environment is true pollution and exerts negative environmental and wildlife health impacts (Cinzano 2002). Artificial light that alters the natural patterns of light and dark in ecosystems is known as 'ecological light pollution' (Longcore & Rich 2004). The linkage between economic activity, population increase and artificial light is evident in several developing regions (Bennie et al. 2013).

Artificial light at night exerts non negligible impacts on fauna and flora (Aube´ 2015) and affects a wide variety of taxonomic groups (Dananay 2013). It has been recently gaining attention in terms of its effects on diurnal and nocturnal animals. Such impacts can extend up to population, community and ecosystem levels (Baker & Richardson 2006). This is because animals and ecosystems are severely affected when the natural cycle of light and darkness is altered by artificial light (Horváth et al. 2009). Artificial light has the potential to alter individual behaviour as well as negatively affect biological rhythms, daily activity and reproduction (Raap et al. 2015). Blue-rich light at night has a greater capacity to alter circadian rhythm and photoperiod in the animal kingdom. Hence, blue-rich light exerts higher negative impacts on wildlife than yellow light, which has lower ecological consequences (International Dark-Sky Association 2010). However, in addition to circadian clocks, night-time lighting also exerts negative effects on time partitioning and immigration/emigration of fauna (Gaston and Bennie 2014). It also affects the social interactions and group dynamics in several animals by altering individual activity patterns of individuals, reducing behavioural synchrony in social processes, affecting the communication between individuals and lowering social competence (Kurvers and Hölker 2015).

Global warming

The current trend of global warming is highly significant because most of it is human-induced and taking place at an unprecedented rate in the past 1,300 years (Whelan et al. 2008). Greater heating effect of higher atmospheric levels of greenhouse gases like carbon dioxide, methane, nitrous oxide and chlorofluorocarbons due to anthropogenic activities mainly cause global warming (US EPA 2016). Annual worldwide emission of such gases has continued to increase, reaching 49.5 billion tonnes (Giga tonnes or Gt) of carbon dioxide equivalents (CO_2 eq) in 2010. This was the highest level till that date. The rate of growth of such gases in the last decade (2000–2010) was double than the rate in any other decade since 1970 (Victor et al. 2014). Under these circumstances, heat-waves and wildfires have been projected to increase, whereas soil-moisture availability is projected to decrease, due to greater evaporation (Engelbrecht et al. 2015).

Biodiversity is impacted due to climate change and many species are likely to suffer declines or undergo extinction (Foden et al. 2013). It is because prominent environmental parameters of climate change such as temperature, solar radiation, humidity, cloud cover and precipitation have implications for biodiversity (Bickford 2010).

1. MATERIAL AND METHODS

Scientific publications on the subject(s) were downloaded from 'Google Scholar' using suitable search words such as 'noise', 'global warming', 'light pollution' and 'amphibians'. Dutta (2018) had also used 'Google Scholar' to obtain scientific publications to review certain aspects of alien plant invasion. However, in this case, information was also collected from a few reliable online sources to supplement the qualitative data obtained from the downloaded peer-reviewed articles. The literature was divided into proper subheads and organized. Thereafter, the combined effect of noise, light pollution and global warming was assessed through categorization, followed by tabulation.

1.1. Categorization

I created seven categories (behaviour, health, movement, distribution, phenology, development and reproductive success), each of which represented a particular amphibian trait. The purpose was to convert qualitative information into empirical data through subsequent tabulation based on these categories and the three problems. These specific categories were selected because they comprehensively summarized the impacts of all the three issues. Thus, this categorization could be done only after understanding all the effects of the three issues on amphibians.

1.2. Tabulation

The problems and the categories were subjected to two types of tabulation that gave rise to two tables (Tables 1 and 2). The first type was based on the seven affected categories. In this type, the three problems were tabulated according to the respective categories they affected (Table 1). From Table 1, the number of problems affecting each of the seven categories could be obtained.

The second type was based on the three problems. In this type, the seven categories were tabulated according to the respective problems that affected them (Table 2). From Table 2, the number of categories affected by each of the three problems could be obtained. Now, the three problems in Table 2 represented three distinct variables. The number of categories affected by a variable (i.e., a problem) was considered as the value of that particular variable. Thus, there were three different variables, each of which had a particular value. Chi-square test was performed among the values of these variables. In other words, the test was performed among the number of amphibian traits affected by noise, light and global warming.

2. RESULTS

2.1. Impacts of Noise

2.1.1 Behaviour (Vocalizations)

Noise interferes with anuran chorus, triggers changes in call rates and suppresses calls of one set of species, which in turn stimulates calling in other species (Sun & Narins 2005). Low-frequency signals are more likely to get masked by anthropogenic noise (Vargas-Salinas 2014). Noise can even cause amphibian male choruses to end before the arrival of the female and thus reduce mating opportunities (Kaiser et al. 2010). In addition, noise can cause deaths in amphibians. For instance, female Wood Frogs (*Lithobates sylvaticus*) are unable to locate male calls, in the presence of noise. Consequently, their movement could be directed towards noisy roads and lead to accidents (Tennessen et al. 2014). In fact, roads result in severe effects on amphibians (Hoskin & Goosem 2010) because even the most subtle road disturbances can exert profound impacts (Maynard et al. 2016). This is evident in female Cope's Gray Frogs (*Hyla chrysoscelis*), which exhibit greater latency and decreased orientation towards the target signal under traffic noise (Bee & Swanson 2007).

Anurans develop behavioural responses that enable the transmission of information and overcome masking of signals in noisy conditions (Vargas-Salinas 2014). They cease to call, call faster or modify frequency or amplitude of calls in such environments (Tennessen et al. 2014). This is evident in the males Bornean Rock frogs (*Staurois parvus*), which modify their amplitude, pitch, repetition rate and duration of notes of advertisement calls in noisy circumstances (Grafe et al. 2012). It is in fact the plasticity in anuran vocalizations, which enables the maintenance of acoustic communication in traffic noise (Cunnington & Fahrig 2010). The Southern Brown Tree Frog (*Litoria ewingii*) emits calls at elevated pitch levels under traffic noise (Parris et al. 2009). Such higher rates of vocalizations elevate amphibian aerobic metabolism up to 22 times, which in turn leads to physiological consequences and behaviour alterations. The latter effect hampers the breeding success. The collective impact affects the overall population growth and persistence. Greater vocal output triggered by noise can exert impacts at both individual and the chorus-levels (Kaiser et al. 2010). The Cauca Poison frog *Andinobates bombetes* has been found to call more often, when traffic noise is lower (Vargas-Salinas & Amézquita 2013). In case of *Boana bischoffi* and *Boana leptolineata*, acoustic parameters are changed during or after the exposure to traffic noise. In *Boana bischoffi*, the advertisement call rate decreases during road noise, and dominant frequency decreases over time. The call length of *Boana leptolineata* changes, depending on the order of noise intensity (Caorsi et al. 2017). On the other hand, males of Pickersgill's Reed frog (*Hyperolius pickersgilli*) change temporal and spectral properties of calls during and after airplanes flyby (Kruger & Du Preez, 2016). Alterations in calling are also evident in Crawfish Frogs (*Lithobates areolatus*) (Engbrecht et al. 2015) as well as Gray Tree frog *Hyla versicolor* and Green Tree frog *Rana clamitans* (Cunnington & Fahrig 2012) in response to traffic noise.

2.1.2 Physiological effects

Noise exposure elevates stress hormone levels and induces immunosuppressive effects in amphibians. Higher levels of noise

Table 1. Tabulation of affecting problems (Noise, Light and Global Warming) according to the affected amphibian categorical aspect

Affected aspect	Affecting problems	Remarks
1). Behaviour	Noise, Light and Global Warming	Amphibian mating calls are altered in response to all the three problems; Light affects foraging
2). Health	Noise and Global Warming	Noise triggers physiological changes; Global Warming exerts heat stress and triggers disease outbreaks
3). Movement	Light	Light impairs vision and hampers movement
4). Distribution	Global Warming	Global Warming changes species range
5). Phenology	Global Warming	Global warming changes timing of breeding
6). Development	Global Warming	Global Warming hampers larval development
7) Reproductive success	Global Warming	Global Warming negatively affects offspring survival

Table 2. Tabulation of affected amphibian aspects/categories according to the affecting problems (Noise, Light and Global Warming)

Affecting problem	Names of affected categories/ aspects	No. of aspects affected by each problem	χ^2-test (among the number of aspects affected by each problem)
Noise	Health, Behaviour	2	$\chi^2 = 3.2$, df = 2, $p > 0.05$
Light pollution	Movement, Behaviour	2	
Global warming	Behaviour, Health, Distribution, Phenology, Development and Reproductive success	6	

and stress hormone negatively affect the vocal sac colouration in the European Tree frog *Hyla arborea*, which in turn also affects sexual selection (Troïanowski et al. 2017). Noise has also been found to increase the secretion of stress-relevant glucocorticoid hormone (corticosterone) in female Wood Frogs (*Lithobates sylvaticus*) and this can have substantial consequences even at the population-level (Tennessen et al. 2014). In White's tree frogs, *Litoria caerulea*, anthropogenic noise not only increases corticosterone concentrations in circulations, but also negatively affects the sperm count and viability. This proves that noise can change physiology and Darwinian fitness (Kaiser et al. 2015).

2.1.3 Additional effects of noise

Noise, in the presence of light pollution, can disrupt the host-parasite interaction, as evident in the case of frog-biting midges (*Corethrella* spp.) and their túngara frog (*Engystomops pustulosus*) hosts (McMahon et al. 2017). In addition, anthropogenic noise causes acoustically communicating Marsh Frogs (*Pelophylax ridibundus*) to leave burrows or change locomotion (Lukanov et al. 2014).

2.2. Impacts of Light

2.2.1 Behaviour (Vocalizations and foraging)

Artificial light affects the calling behaviour in several amphibian species in natural, mixed assemblages. The number of calling individuals and call index decreases in frogs in response to the acute light input (Hall 2016). When frogs stop mating calls upon exposure, their reproductive capacity is reduced (Longcore & Rich 2004; Chepesiuk 2009). The effect of light pollution is evident in the male green frogs (*Rana clamitans melanota*), which produce fewer advertisement calls and move more frequently in the presence of artificial light, compared with ambient light conditions. Its behaviour is affected by artificial light in a manner that has the potential to reduce recruitment rates and thus affect population dynamics (Baker & Richardson 2006). On the other hand, male tree frogs, *Smilisca sila* (Hylidae) emit fewer and less complex calls, and tend to call from more concealed sites, in the absence of illumination (Tuttle & Ryan 1982).

Another behaviour affected by light is foraging, as evident in certain nocturnal frogs, like Cane Toads (*Bufo marinus*), which forage regularly under enhanced illumination near buildings. Certain anurans are also attracted to streetlamps at night due to a greater availability of insects for hunting under illumination. On the contrary, the fossorial Red-backed Salamander (*Plethodon cinereus*) forages less in brighter areas; compared with darker areas, it also displays greater visual threats in illuminated areas (Rich & Longcore 2006; Perry et al. 2008). The preference for foraging site is not affected by light in Wood Frogs (*Rana sylvatica*), but Blue-spotted Salamanders (*Ambystoma laterale*) prefer deciduous litter in dark and coniferous litter under greater illumination. Artificial lighting can also attract such salamanders to substrates that are not usually preferred (Feuka et al. 2017).

2.2.2 Vision and movement

Orientation is the primary determinant of successful amphibian movements between habitats (Mazerolle & Vos 2006). However, nocturnal car traffic emits light and noise that trigger immobility in amphibians at the approach of the vehicles. Consequently, amphibians become highly vulnerable to road mortality (Mazerolle et al. 2005). Street lighting also increases this risk by attracting migrating amphibians (van Grunsven et al. 2017). This is relevant in the case of pond-breeding amphibians, which move across the landscape to their breeding, summering or hibernation grounds and thus, frequently encounter roads. In case of certain species (e.g., American toads *Bufo americanus*), the rate road mortality increases with an increase in traffic intensity, whereas in others, the mortality is greater in lower (Spring peeper *Pseudacris crucifer*) or moderate (e.g., Ranid frogs) levels of traffic (Mazerolle 2004). In fact, several amphibians are killed by traffic on their way to reproduction sites during spring migration in Western Europe (van Grunsven et al. 2017).

A sudden increase in illumination due to artificial lighting reduces the visual capability of frogs, which might require hours to recover (Buchanan 1993). Frogs might also be attracted to light after such recovery (Jaeger & Hailman 1973). In addition, night lighting can stimulate phototactic behaviour, which inhibits movements of amphibians to and from breeding areas (Longcore & Rich 2004). Further, alteration in the polarization of light due to human activities also affects amphibian movements as they have well-tuned polarized vision. Changes in polarization occur due to interaction with human-made structures (Horváth et al. 2009).

2.2.3 Additional effects of light

Light facilitates predation by visually orienting predators, and hence, can increase their activities. Consequently, activities of prey could be reduced due to a higher risk of predation. Diurnal and crepuscular predators could become facultative nocturnal predators under suitable lighting (Gaston et al. 2013). On the other hand, female Tungara frogs (*Physalaemus pustulosus*), under increased levels of light, become less selective about mate choice and tend to mate quickly and avoid predation risk (Rand et al. 1997).

2.3. Impacts of Climate change

2.3.1 Population decline and extinctions

Decline and extinction of amphibian populations on account of climate change has taken place all over the world (Pounds et al. 2006; Araujo et al. 2008; D'Amen & Bombi 2009). Species with a lower ability to disperse (Ochoa-Ochoa et al. 2012) and narrow tolerances for temperature and moisture (Olson & Saenz 2013) are at a high risk. About 75% of amphibian and reptile communities have declined in La Selva Costa Rica during the last 35 years and climate-driven loss of leaf litter has been cited as a cause (Whitfield et al. 2007). A decline of 50% amphibian population in Yellowstone National Park has been correlated with temperature elevation and precipitation reduction over the last 60 years (McMenamin et al. 2008). Unusual frost and weather conditions have led to the disappearance of amphibians in south-eastern Brazil (Heyer et al. 1998) and Costa Rica (Crump et al. 1992) respectively, whereas droughts have caused population declines of Brazilian frogs in the Atlantic mountains (Weygoldt 1989).

According to Bickford et al. (2010), amphibians would be adversely affected by the projected rapid climate change. They state that within 50 years, the capacity of amphibians to adapt to climate change in Southeast Asia would be surpassed; indicating greater extinctions. However, up to 66 percent of amphibians identified by a study as highly vulnerable to climate change is not in the IUCN Red List of Threatened Species. These species have shown a sharp decline in the population or a shrinking geographic range (Foden et al. 2013). Climate change even combines with other factors such as UV-B radiation and contaminants and leads to complex implications that causes accelerated amphibian population declines and extinctions (Blaustein 2010).

According to Foden et al. (2008), 52% of amphibian species are vulnerable to climate change due to specialized habitat requirements, limited dispersal ability and water-dependent larvae. In this regard, amphibians depending on ephemeral ponds, coastal wetlands, arid and semi-arid systems, or alpine areas are at a high risk (Kundzewicz et al. 2007; IPCC 2007; Rios-López 2008; Brooks 2009).

2.3.2 Changes in distribution

Due to climate change, the distribution of amphibians undergoes changes (Munguı´a et al. 2012). Several amphibians are also likely to expand distributions, as warming in the colder ranges creates scope for colonization. Inability to disperse causes species to lose range (Araujo et al. 2006). This is understood from the fact that the suitable habitat of amphibians is likely to be shifted to higher altitudes and latitudes due to climate change in China (Duan et al. 2016). In central and western South America, amphibians have also been predicted to undergo a higher range contractions by 2071 due to climate change (Lawler et al. 2010). In fact, changes in temperature patterns have been associated with altitudinal range increase in amphibians after the retreat of Andean glaciers as well as in Malagasy massif (Seimon et al. 2007; Raxworthy et al. 2008). Moreover, global warming has brought about changes in patterns and intensity of El Nino Southern Oscillation, an event that impacts biological productivity of the ocean, as well as community distribution near shores (Carey & Alexander 2003).

2.3.3 Phenological changes

Phenology in some amphibian species has been altered by climate and this is likely to expose them to fluctuating weather conditions (Olson & Saenz 2013). This is because reproduction is closely linked to environmental cues and climate change can alter the timing of reproduction in many species (Blaustein 2010). Most temperate amphibian species remain inactive for a major part of the year. Upon subtle temperature and moisture increments, they immediately proceed to breed in water bodies. In such amphibians, global warming can induce early breeding as temperatures increase (Araujo et al. 2006).

The fact that global warming triggers earlier breeding in amphibians is evident from the changes in the phenology of Fowler's Toads (*Anaxyrus fowleri*), which is a late-breeding of spring (Green 2016). Amphibians have exhibited early breeding in Japan (Kusano 2008) and New York (Gibbs and Breisch 2001) and the fact is also evident in the newts of genus *Triturus* (Chadwick et al. 2006). Although such preponed amphibian breeding has been recorded, the resulting consequences have not yet been understood (Carey & Alexander 2003).

2.3.4 Behaviour (Mating)

Frequency of mating calls and mating success in amphibians are influenced by temperature fluctuations (Gerhardt & Mudry 1980).

2.3.5 Reproductive failure

Amphibians are highly vulnerable to precipitation alterations as water availability is necessary for the survival of their eggs and larvae (Araujo et al. 2006). Fluctuations in rainfall also affect amphibian egg-laying (Caldwell 1987). Greater climatic fluctuations can also lead to seasons witnessing episodic mass mortality or 'bust' years (Olson & Saenz 2013).

In addition, frogs that lay their eggs on land could experience heavy mortality arising due to lower soil moisture as well as elevated evaporation in dry and hot environments (Bickford et al. 2010). Early drying up of habitats due to changes in climate results in mass mortality of eggs, tadpoles and metamorphosing individuals (Blaustein & Olson 1991). Moreover, this can also increase exposure to predators because when the water boundary recedes, amphibian refuge is lost (Olson & Saenz 2013). Amphibians, depending on ephemeral ponds and streams for reproduction, are the most vulnerable (Olson & Saenz 2013). In addition, warmer temperatures can also upset sex-determination in some species (Eggert 2004).

2.3.6 Larval development

Larval gametogenesis and growth rates as well as post-metamorphic growth rates dependent on temperature and thus, are affected by global warming (Beebee 1995; Carey et al. 2003). Increased water loss from bodies of metamorphosed amphibians under higher temperatures, along with their inability to produce concentrated urine, increases the risk of desiccation (Shoemaker et al. 1992). Global warming is also likely to influence the availability of autotrophic food organisms consumed by several tadpoles due to the increase in primary production and nutrient cycling occurring due to increased temperatures (Meyer et al. 1999).

Warming decreases the level of dissolved oxygen in aquatic habitats that hampers embryonic and larval development and accelerates/suppresses hatching (Rome, Stevens and John-Alder 1992; Mills & Barnhart 1999). Moreover, under low oxygen levels, larvae tend to move to the water surface more frequently to collect air; consequently, lesser time is used for foraging and growth and development is hampered (Wassersug & Seibert 1975).

2.3.7 Incidence of diseases

Climate change indirectly facilitates infectious disease epidemics (Carey & Alexander 2003). It can alter the ranges of pathogens, hosts and vectors, as well as the mode of disease transmission and alter pathogen-host dynamics in amphibians (Blaustein et al. 2010). Global warming has already triggered certain pathogen outbreaks that have led to mass extinctions in the recent times (Pounds et al. 2006). Monteverde Harlequin Frog (*Atelopus* sp.), Golden Toad (*Bufo periglenes*) and about 67% of approximately 110 species of genus *Atelopus*, endemic to the American tropics faced extinction due to Chytrid Fungus (*Batrachochytrium dendrobatidis*). This has been linked with rising temperatures due to global warming that shifted this pathogen to these areas, leading to outbreaks (Pounds et al. 2006). In fact, increasing temperatures in higher altitudes are creating conditions optimum for the accelerated outbreaks of *Batrachochytrium* (Pounds et al. 2006). On the other hand, decrease in depths of water bodies due to climate change increases exposure of amphibian embryos to ultraviolet (UV-B) radiation, which in turn elevates infection risk by *Saprolegnia ferax* causing greater egg mortality in amphibians (Kiesecker et al. 2001).

2.4. Direct impact of heat

Amphibians are ectothermic, and hence are affected directly or indirectly by changes in their climate (Araujo et al. 2008). This is because amphibian body temperatures are determined primarily by heat exchange with air, water and/or soil or solar heat gained from the sun (Hutchison & Dupré 1992). Skin permeability, biphasic lifecycles and shell-less eggs are some features that also make amphibians vulnerable to climatic changes (Carey & Alexander 2003). Elevated temperatures can alter water regulation, oxygen uptake, emergence, mating, development, metamorphosis, growth and sex reversal in amphibians (Feder & Burggren 1992).

2.4.1 Combined effect of noise, light pollution and global warming

Tabulation of the seven categories (behaviour, health, movement, distribution, phenology, development and reproductive success) and the three problems, led to the assessment of the combined effects. When the three problems were tabulated according to the respective categories (i.e., traits) they affected, amphibian behaviour was found to be affected by all the three issues. This was followed by health, which was affected by two problems (noise and global warming). All the remaining five traits were affected by only a single problem (Table 1).

When the seven categories were tabulated according to their respective affecting problems, global warming was found to affect six categories, whereas noise and light were found to affect two categories each. There was no significant difference ($\chi^2 = 3.2$, df = 2, $p > 0.05$) in the number of amphibian categories affected by noise, light and global warming (Table 2). The overall negative impacts of the three issues have been depicted in Fig. 1.

3. DISCUSSION

The literature survey and its analyses very well prove that noise, light and global warming are multidimensional environmental forces that affect amphibians at different levels of the biological organization. With greater urbanization and human development, their negative impacts are likely to intensify. Amphibians exhibit moderate relative responses to water-borne toxins and are not particularly sensitive to chemical contaminants (Kerby et al. 2010), but they are highly vulnerable to the three problems discussed. An important drawback in this regard is the fact that alterations in amphibian distribution and community assemblages under changing habitats due to human modification have not been understood (Kruger et al. 2015).

The acoustic mode of communication makes anurans highly vulnerable to noise. This is because noise is an important determinant of such a communication, apart from the power generated from source of sound, environmental features through which signals propagate, and receiver sensitivity (Penna et al. 2013). In this regard, the acoustic adaptation hypothesis states that communication signals have been shaped by evolution in a manner that minimizes degradation and maximizes contrast against the background noise (Vargas-Salinas & Ame´zquita 2013). When such signals are obstructed by noise, mating in amphibians is hampered. This is because

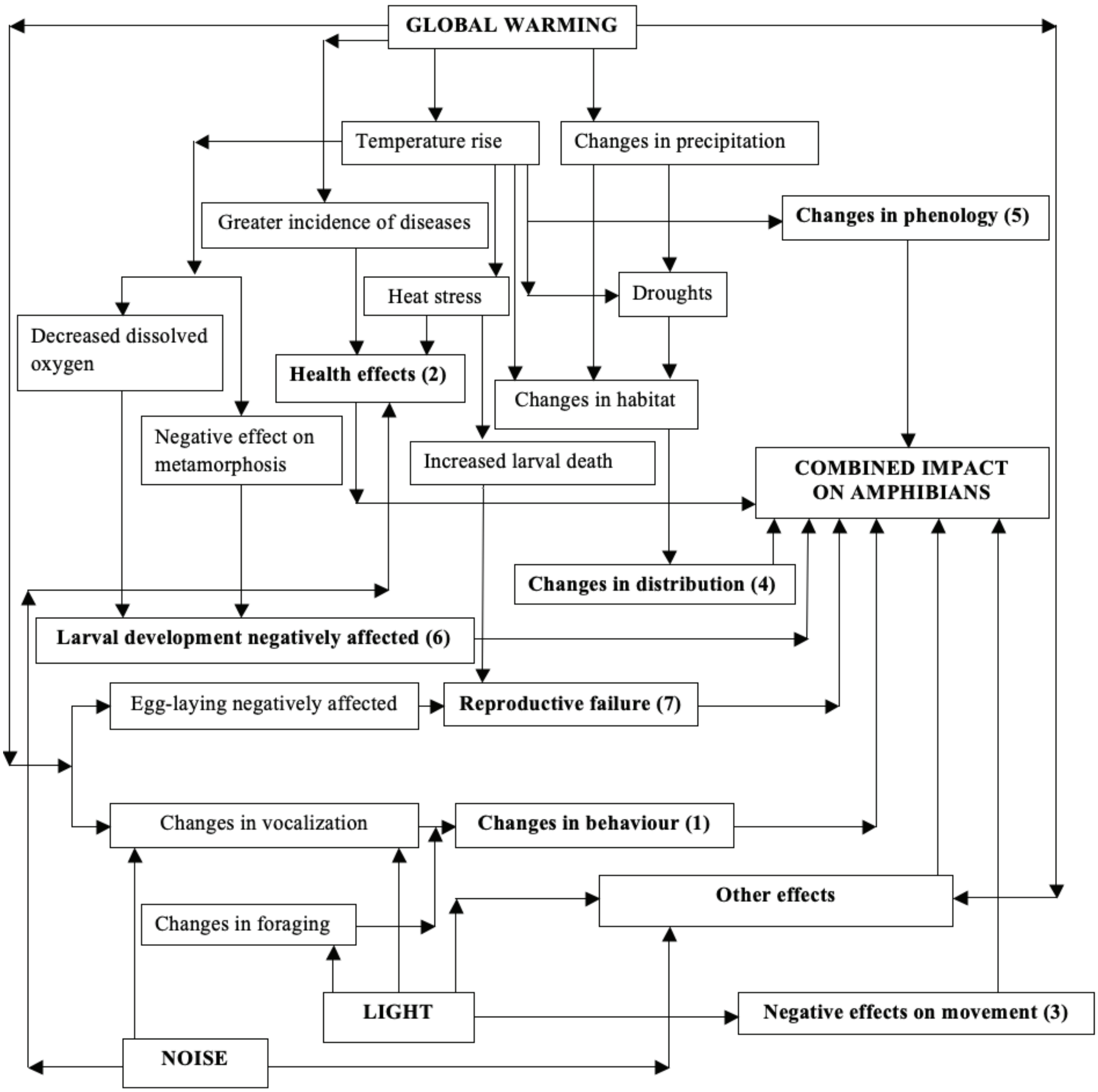

Figure 1. Combined impact of the noise, light pollution and global warming in amphibians (Numbers in parentheses correspond to the serial numbers in Table 1)

the loud male sexual advertisement signals are required to elicit responses from reproductive females, communicate with other males during interaction over calling sites and territories (Vélez et al. 2013). In response to noise, frogs elevate their call amplitude, an aspect which requires further study (Schwartz & Bee 2013). Noise also affects lizards in which sensitivity is influenced by changes in temperature and is usually the highest in their ranges of activity (Campbell 1969).

There is a necessity of adequate planning of development to avoid the negative effects of noise. If this could not be achieved, noise control practices should be planned along with the development of infrastructure. An inventory of wildlife that could be affected by noise should be prepared, their biological requirements should be understood and noise production should be regulated according to their behaviour and needs in general. This could include strategies to reduce at particular seasons. However, an important obstruction in understanding the effects of noise is limited knowledge about the hearing capacity of animals and characteristics of emitted sounds in natural environments (McGregor et al. 2013).

Amphibians and reptiles have not evolved with artificial night lighting, and hence, their physiology, behaviour and ecology are prone to the problem (Perry et al. 2008). Different species exhibit different activity patterns under different light conditions, and hence, alterations in lighting can increase or decrease competition among species. A native gecko species in

Hawaii gets out-competed by another species during the presence of clustered insect distributions caused by lights (Petren & Case 1996). Artificial night lighting can also cause disorientation in marine turtles during sea-finding (Tuxbury & Salmon 2005).

Lights that match the normal, nocturnal spectra have the least effects on anurans, and hence, should be used in amphibian habitats (Buchanan 2006). Trees can also be helpful in mitigating the impacts of excessive artificial lighting. In fact, the role of tree canopy with respect to light is evident in natural ecosystems. This could be understood by the fact that changes in canopy coverage influence light penetration, which in turn affects amphibian population dynamics in wetlands within forested biomes (Halverson et al. 2003). In fact, gradients arising due to canopy cover over ponds influence the larval distribution among ponds (Skelly et al. 2002). Proper plantation of trees taking into consideration the topography of an area and the source of light could be an efficient mitigation measure. In addition, comprehensive investigations on the ecological light pollution with the collaboration of physical scientists and engineers are also required (Longcore & Rich 2004). Halfwerk & Slabbekoorn (2015) have suggested an integrated multimodal approach in order to understand the complete ecological consequence of human activities on animal performance and perception. They have emphasized that more empirical studies should be conducted on the covariance among sensory conditions, such as, correlation between noise and light pollution.

Global warming can severely affect amphibian fauna because changes in temperature, precipitation, humidity and soil moisture affect their physiology, behaviour and ecology of (Blaustein 2010). It also increases pathogen development and survival rates, disease transmission and host susceptibility (Harvell et al. 2002). In fact, climate change has been promoting infectious disease and eroding biodiversity; thus, reduction in greenhouse-gas concentrations is required (Pounds et al. 2006). To add to this is the limited dispersal ability in amphibians and reptiles, which makes these species further more vulnerable to changes in climate (Araujo et al. 2006). Therefore, future projected climate changes can pose challenges for the surviving amphibian populations (Carey & Alexander 2003), leading to population declines and extinctions. In fact, lethal temperatures have already been measured in a number of amphibians across several habitats (Rome et al. 1992). The risk of extinction is greater in higher elevation species as land or habitat availability decreases with increase in altitude (Benning et al. 2002). Climate change has been projected to cause considerable damage to the Appalachian Mountains in US which is a hotspot for salamander biodiversity (Milanovich et al. 2010).

The risk of extinction is higher in case of endemics and restricted range species that have minimal or no space for upward movement or which are incapable of shifting upwards due to physiological effects of geographical gradients (Lawler et al. 2009). However, direct causal relationships between amphibian declines and the correlated climate events need further research to be understood (Carey & Alexander 2003). In addition, greater knowledge of the environmental factors that enable organisms to get rid of winter dormancy will lead to a greater understanding of long-term phenological trends under climate change (Green 2016).

Reptiles are also affected by climate change, but the implications of warming on reptiles have not been properly studied (Araujo et al. 2006). Reptiles neither have the mobility of birds nor are capable of regulating body temperature and are only able to move minimally under changing climates (US Geological Survey 2014). Climate change leads to upward migration and biased sex ratio in reptiles (Janzen 1994). Some reptiles have been projected to suffer severe decrease in ranges between 2010 to 2099; for example, Plateau Striped Whiptail (*Aspedoscelis velox*), Arizona Black Rattlesnake (*Crotalus cerberus*), Common Lesser Earless Lizard (*Holbrookia maculata*) and Common Chuckwalla (*Sauromalus ater*) (US Geological Survey 2014). Mitigation of climate change can only be achieved through the reduction of greenhouse gas emission controlled through proper regulations. There is also a need to change attitudes on the interaction with and utilization of biological systems (Bickford et al. 2010). For the proper conservation under climate change, critical habitats for amphibian protection should be identified (Guisan et al. 2013).

When the combined effect of the three problems was considered, amphibian behaviour was identified as the most vulnerable aspect. Calling was found to be at a high risk in this context because it was affected by all the three problems. This can have severe negative consequences in mating because amphibian calls are crucial signals to attract mates and consequently reproduction would be affected (discussed earlier). This is a serious issue because reproduction is the main factor that efficiently maintains variation and inheritance and is the primary requisite of organic evolution (East 1918).

The fact that there was no significant difference in the number of amphibian traits affected the three problems indicated that the negative effect of global warming would not be the primary determining factor in determining the overall negative impact. In other words, the effect of light and noise would not be negligible. On the contrary, a significant difference would have indicated that global warming would be the main determinant of the combined impact of the problems because it affected the highest number of amphibian traits. Thus, no problem should be neglected and mitigation measures should be taken for all the three. However, while devising such measures, habitat fragmentation should also be considered because decrease in landscape connectivity due to fragmentation and habitat loss affects amphibian assemblage and reversal of such changes is an important conservation strategy (Lehtinen et al. 1999). Moreover, there could be a number of ecological consequences of fragmentation and habitat loss that could actually magnify the impacts of the above issues and vice versa. In addition, there are anthropogenic activities that could have their own consequences on amphibians. For instance, peat mining changes the activity and movement of amphibians in bog fragments. The ability of larger species to survive in such disturbed environments is better than the smaller species, as they are less sensitive to desiccation (Mazerolle 2001). Thus, it is understood that the problems are required be studied for the combined assessment of impacts to devise mitigation measures. However, while doing so, other ecological problems and existing anthropogenic activities should be taken into account. An effective solution can be then be devised and amphibians can be conserved.

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