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Review:
Climate-induced hydrological changes and the ecology of tropical freshwater biota

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Abstract. *Sunardi, Wiegleb G. 2016. Climate-induced hydrological changes and the ecology of tropical freshwater biota. Biodiversitas 17: 322-331.* Climate change is believed to pose adverse effects to biodiversity of aquatic systems, with no exception of those in tropical areas. However, next few decades species extinction is suggested as dark future as we lack researches uncovering how climate change threats the aquatic biota. Unluckily, the tropical freshwater systems are expected to suffer more severe impacts of climate change, from heavy floods or extended drought than do the boreal areas. A comprehensive understanding of biota' performance in face of climatic pressures, will guide the further necessary researches. This paper presents a review on the available researches addressing ecological effects of the most influential climatic parameter in tropic area, the hydrological regime, on freshwater biota. The research reveal that the extreme water fluctuations induced by climate change have negatively affected the performance of freshwater biota. In the next few decades, climate change seems to remain as one of the main threats for freshwater ecosystems, and is responsible for the lost of its biodiversity.

Keywords: Biota performance, climate change, drought, flood, tropical freshwater

INTRODUCTION

Global change has been shown and predicted to have major effects on biodiversity at global, regional, and local scales, although global change constitutes a number of different forms of anthropogenic impacts (Sala et al. 2000), including land use alterations, nitrogen deposition, and invasions of exotic species. In other words, changes in climate and climate variability would, somehow, significantly affect natural ecosystems, and may pose additional threats to the already-stressed ecosystems. Furthermore, the effect of future climate change on biodiversity has been predicted to be unprecedented as well, with 15-37% of terrestrial species possibly becoming extinct due to climate change alone in the next 50 years (Thomas et al. 2004), and a similarly dark future has been suggested for freshwater species in the next few decades (Xenopoulos et al. 2005).

Freshwater ecosystems are vulnerable to global change. Important global climate variables that are expected to change in the next decades with respect to freshwater habitat are air temperature and precipitation (Mitchell et al. 1990). Changes in these variables will affect water temperature, water quantity and water quality variables of freshwater environments which are the three primary linkages between climate and freshwater organisms (Regier and Meisner 1990).

Climate change pushes species out of their ecological synchrony and environmental landscape. This influences not only species distributions or community structure, but also the services they provide to ecosystems. Understanding how species' performances change along with the environmental gradients is worthwhile. This is particularly important in aquatic systems, where shifts in habitat quality associated with environmental perturbations threaten the integrity of aquatic biota (Strayer et al. 2004).

The magnitude of impacts and responses of aquatic ecosystems, however, differ between boreal and tropical area with regard to the global change. This is due to climatic variation between the two areas. In the tropics, the annual variation in air temperature is smaller, but there is a large and predictable annual variation in precipitation (Lowe-McConnell 1987). The seasonal precipitation cycle produces wide ranges in river flow rates and water levels, which directly alters the amount of freshwater habitat available for biota and indirectly alters many critical characteristics of that habitat (eg, O_2 levels, turbidity, food availability, etc.).

The increase in global temperature, nevertheless, will lead to a more vigorous hydrological cycle, with changes in precipitation and evapotranspiration rates regionally variable. Warming accelerates land-surface drying as heat goes into evaporation of moisture, and this increases the potential incidence and severity of droughts, which has been observed in many places worldwide (Dai et al. 2004). In tropical systems, evaporation and evapotranspiration often already exceed precipitation in the dry season (Irion and Junk 1997). In weather systems, convergence of increased water vapor leads to more intense precipitation and the risk of heavy rain and snow events, but may also lead to reductions in duration and/or frequency of rain events, given that total amounts do not change much (see Trenberth 2005). In such case, the tropical areas are expected to suffer more severe impacts of climate change, from heavy floods or extended drought than do the boreal areas.

Despite the increase of research on the topic, we lack a comprehensive understanding of the consequences of extreme precipitation fluctuation (as distinct from seasonal climate) on the ecology of tropical freshwater biota. The aim of the present article is to complement the existing information by reviewing current knowledge of climate change effects, paying particular attention on hydrological regime, on species' performances in tropical freshwater.

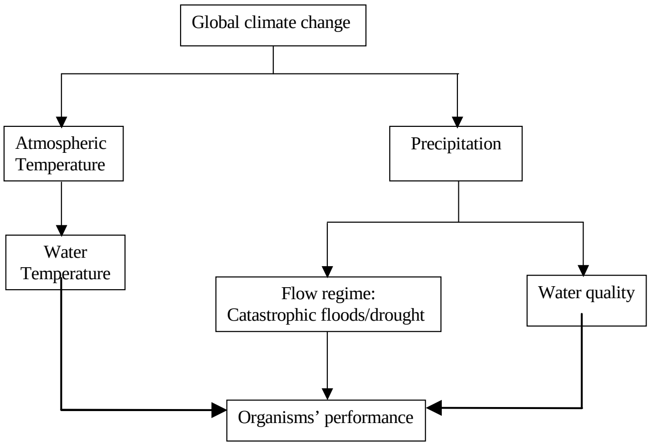

Figure 1. Key climate-related parameters affecting global freshwater organisms

KEY CLIMATE-RELATED PARAMETERS

Aquatic ecosystems are vulnerable to changes in quantity and quality of their water supply, and it is expected that climate change will have a pronounced effect on global freshwater through elevated temperature and alterations in hydrological regimes with great global variability. As a matter of fact, aquatic organisms have to deal with a wide variety of environmental factors simultaneously; however, temperature, water quantity and water quality are regarded as the most fundamental climate-related factors (Figure 1).

In tropical regions, fluctuations in rainfall often represent the strongest seasonal variation, and change the environment to an extent comparable to temperature in temperate areas (Jacobsen and Encalada 1998). Variation in rainfall that affects stream discharge is among the most important sources of natural disturbances (Taylor et al. 1996). Flow regimes range from spates or peak flows during the rainy season through to zero flow in the dry season. The shape and size of river channels, the distribution of riffle and pool habitats, and the stability of the substrate are all largely determined by the interaction between the flow regime and local geology and landform (Newbury and Gaboury 1993). In turn, this complex interaction between flows and physical habitat becomes the major determinant of the distribution, abundance, and diversity of stream and river organisms (Nilsson and Svedmark 2002).

It is reported that effects of climatic variability on hydrology can be particularly devastating, causing changes in water chemistry, stream size, water temperature, streambed structure, streambed substrate and stream flow (see Medeiros and Maltchik 2001; Starks et al. 2014). Hence, such environmental variation can dramatically alter the living conditions and aquatic habitats within the water, affecting much of the aquatic fauna inhabiting streams (Moyle and Vondracek 1985; Taylor and Warren 2001). Biota, in particular those living in vegetated riparian areas, respond differentially to water-level dynamics, either directly or indirectly. Direct effects on the biological communities include physical disturbance by wave activity. Indirect effects include the reworking of substrates (which can enhance or restrict colonization by vegetation, and which in turn depends on silt accumulation to establish roots), and alteration of habitats suitable for aquatic flora and fauna. Any significant changes in the water level of a lake will affect not only the physical processes, but also the biological productivity. Therefore, water level fluctuation might have an overriding effect on Lake Ecosystem health and integrity (Furey et al. 2006; Leira and Cantonati 2008).

In addition, ambient temperature is undoubtedly among the most important for ectotherm ontogeny because of its pervasive effects on biological rate processes, altering nearly all physiological functions (Deutsch et al. 2008; Kingsolver 2009). It has been known for more than a century that biochemical reaction rates, metabolic rates, and nearly all other rates of biological activity increase exponentially with temperature. In tropical area, however, seasonal temperature variability is small (Meisner and Shuter 1992), and it seems does not pose profound effects on organism' performance as does in boreal areas. Therefore, this paper will not deal with the effects of inclined temperature on freshwater organisms.

IMPACTS OF FLOOD ON BIOTA

Water flow in aquatic ecosystem, particularly lotic, is often subject to a high short-term variability. This short-term variability may be caused by high precipitation events in the catchment. Hydroperiod and flood frequency (Medley and Havel 2007), as well as high water flow (Godlewska et al. 2003) have been recognized as significant factors structuring communities.

This suggests that hydrology has a significant effect on both species richness and community structure of planktonic communities in rivers, streams, floodplain ponds and lakes. Flood events often act as disturbances that interrupt the succession in planktonic community (Mulyaert et al. 2001); even a short flood event may have effects on the planktonic ecosystem that last for weeks.

Nevertheless, the research showed that the responses of the planktonic communities differ from site to site showing its dependence to other biotic and abiotic factors. Some groups of plankton may respond positively or negatively, while some others do not show clear response; e.g. Chlorophyll a concentration and abundance of bacteria, oligotrich ciliates and crustacean zooplankton did not respond clearly to the flood event (Mulyaert and Vyverman 2006).

It is evident that flood waters transport large amounts of suspended solids and nutrients into lakes. An increase in the concentration of suspended matter in a lake leads to greater light attenuation and thus to a decrease in primary production (Lloyd et al. 1987). High concentrations of abiogenic turbidity can light-limit phytoplankton photosynthesis and therefore restrict biomass development (Holst and Dokulil 1987; Dokulil 1994). In most cases, an increase in nutrient input causes a consequent rapid increase in algal biomass. This is especially true of oligotrophic lakes (Thomas 1973). However, in several lakes, an impoverishment of the algal standing stock and a decrease in the phosphorus concentration are observed following events involving the discharge of suspended sediment into the lake, despite the fact that the turbid inflow transports a large load of particulate phosphorus into the lake (Sampl 1986). This is due to the phytoplankton is sedimented out after flood event, as the phytoplankters and suspended matter do coagulate efficiently (Elber and Schanz 1990), result in a decrease in primary production and phytoplankton biomass. Additionally, the negative responses can occur under condition of prolonged floods because the flood pulse can have dilution effects on nutrient, so that a significantly lower phytoplankton biomass is established (Keckeis et al. 2003; Mihaljević et al. 2009).

Grobbelaar (1992) and Dokulil (1994) suggest that the ratio of mixing to euphotic depth is one of the most important factors affecting overall productivity mainly in turbid waters. In these water bodies the aphotic portion is large compared to the euphotic zone and determines the relative time spent in the dark by the algae. The ratio of euphotic to mixing depth is considered to be the most important factor affecting overall productivity, while nutrients are of secondary importance only. Nutrients influence productivity only when a more favorable underwater light regime prevails, such as prior to the flooding. Energy available for phytoplankton growth is strongly regulated by underwater light availability which depends on the critical mixing depth, fluctuating light intensities and algal circulation patterns.

Godlewska et al. (2003) reported that shifts in phytoplankton distribution (from hypolimnion into the whole water column) and species composition were observed. In one case, this is because of high water flow eliminated large species of cladocerans and copepods, and favored development of rotifers; while in another case, plankton animals may concentrate at different depths in the water column before and after the flood because they are transported to different locations by water currents. Dirnberger and Threlkeld (1986) found that during the period of flooding most zooplankton populations declined and the distributions of remaining individuals deepened; greatest population losses occurred between 0 and 7m depths where most zooplankton had been concentrated prior to the flood. The changes in distribution may be results from search for the right compromise between two conflicting demands: to maximize feeding and to avoid predators (Gliwicz 1986).

On the other hand, floods can have positive impacts on planktonic communities. Dispersal among patches is important to the long-term viability of species in metapopulations, and flood connections can enhance the viability of certain species (Jenkins 1995). Immigrants with differential competitive ability can be introduced into communities which releases local communities from competitive exclusion, shifts local dynamics, and enhance long-term persistence (Leibold et al. 2004). Flooding can introduce new species (Havel et al. 2000), but intense flooding can wash out entire populations (Baranyi et al. 2002). Turbulence, which increases in high flood, can also have direct effects on reduced grazing rate (Miquelis et al. 1998) and food selectivity of zooplankton (Vanderploeg 1994).

In river, increase in discharge leads to increased drifts. Downstream invertebrate drift is a normal feature in lotic systems and facilitates the recolonization of denuded areas of a stream (Brittain and Eikeland 1988). However, disturbances notably flooding have an important role in regulating the distribution, abundance and coexistence of macroinvertebrate (Resh et al. 1988). Significant reductions in macroinvertebrate density have been recorded after scouring floods (Robinson et al. 2004). While moderate disturbance may encourage diversity in many systems (see Smith and Brown 2006). In regulated river reaches below dams, it was reported that sudden increases in flow can cause catastrophic downstream drift (Layzer et al. 1989).

The most frequently reported effect of sedimentation associated with floods is an increase in drift density (e.g., Doeg and Milledge 1991; Suren and Jowett 2001), which may account for the loss of individuals and species in response to a loss of suitable habitat and changes to the food web (Rabeni et al. 2005). In addition, high water flow can also be acute for invertebrate; Doeg and Koehn (1994) identified a reduction in total number of benthic macroinvertebrate taxa and abundance, after a flushing event that increased suspended solid concentration. Pruitt et al. (2001) reported that total suspended solids concentrations greater than 284 mg L^{-1} resulted in biological impairment of invertebrate communities, while a concentration of 58 mg L^{-1} or less during storm flow provided an adequate margin of safety and were protective of aquatic invertebrates. Variability in tolerance to suspended solid could be explained by sediment particle characteristics, water temperature, species differences and other stressor that might have synergistic effects (Bash et al. 2001). In addition, the degree of turbidity associated with flood events has been known to affect the response of benthic invertebrate to flood. Present study report that the magnitude of response of macroinvertebrate community to the flood is most severe in the non-turbid, upper main river and tributaries where benthos community is dominated by the most sensitive Ephemeroptera, Plecoptera and Trichoptera species (Miserendino 2009).

Sediment transport and deposition are processes that are a natural part of the stream environment and play a major role in structuring stream habitats. However, streams are vulnerable to increased sedimentation brought about by altered land uses in the surrounding catchments, with detrimental effects on benthic stream communities. The exacerbation of erosion and sedimentation may be particularly striking in the tropics (Newcombe and MacDonald 1991; Wood and Armitage 1997) where extreme climatic conditions can prevail and aquatic systems are increasingly under threat. However, ways of how sediment affects aquatic ecosystems are various depending on the shape, size and density of the particles; their potential for microbial colonization; the velocity, temperature, flow and turbulence of the water (Hellawell 1986); and the presence of associated factors, such as nutrients (Lemly 1982). Increased levels of sedimentation can bury macroinvertebrates and their habitats (Wood et al. 2001; Wood et al. 2005) leading to shifts in the structure of the habitat and its associated fauna (e.g., Ryder 1989).

Sedimentation has been shown to induce behavioral response of macroinvertebrate, where macroinvertebrates actively avoid substratum coated with excessive fine sediment (McClelland and Brusven 1980; Connolly and Pearson 2007). It is predicted that the upland fauna would be more sensitive to sedimentation because it would naturally experience lower exposure to sedimentation than the lowland fauna; such different response has been demonstrated in both, the mesocosm and in-situ experiments (Connolly and Pearson 2007). Fine sediment deposition can cause shifts in the community structure through the loss of sensitive species, particularly those requiring coarse substrata for attachment or feeding, and through increases in the abundance of burrowing animals, such as some Chironomidae and Oligochaeta (Hellawell 1986). Sedimentation can also affect the filter feeders, scrapers and collector through ingestion of inorganic when feeding, with a negative effect on nutrition and growth (Ryder 1989). Fine silt deposit trapped by periphyton can reduce photosynthesis (Yamada and Nakamura 2002), and thus algal availability to grazers (Donohue and Irvine 2004). There may also be indirect effects of sedimentation transmitted through top-down effects of predators, such as fish and crayfish (Schofield et al. 2004). However, several studies have shown that changes in abundance rather than diversity are commonly associated with sedimentation (e.g., Lenat et al. 1981, Wagener and LaPerriere 1985).

In large lenthic ecosystem, water level fluctuation plays a role more importantly than does flow regime. Such effects on ecosystems are very complex, and the biological effects in lakes are greatest in shallow water and littoral areas, where even small changes in water levels can result in the conversion of large areas of a standing-water environment in air exposed habitats (Leira and Cantonati 2008). The potential effects of lake-level changes have been judged by impacts at the physical level, i.e. transparency, sedimentation patterns, erosion; at the species level, i.e. target species, and by indicators at the ecosystem level, i.e. carrying capacity and biodiversity (Leira and Cantonati 2008). The fluctuation of water level can alter the lake morphometry and transform the characteristics of the sedimentation zone (erosion, transportation, accumulation; Håkanson 1977), thereby water-level drawdown enhances sediment erosion and has the potential to fundamentally change littoral sediment and biogeochemical characteristics (Furey et al. 2004). The water level fluctuation cause changes in the littoral area available for benthic macroinvertebrate. The lost of littoral vegetation due to inundation or the establishment of emergent species from seed during low water is always accompanied by changes in invertebrates and amphibians (Eulis et al. 2004).

The functioning of shallow lakes and floodplains is supposedly very sensitive to water level changes. Moreover, littoral plant communities in shallow lakes located in semi-arid to arid regions appear to be particularly susceptible to water-level fluctuations (Beklioglu et al. 2006). High water level can facilitate the expansion of submerged vegetation that from which some benthic invertebrates take benefits.

The effects of water level fluctuation on benthic macroinvertebrate are very subtle, both directly and indirectly (Leira and Cantonati 2008). Direct effects on invertebrates include changes in the structure and dynamic of taxa that cannot withstand dry periods which subsequently lead to a limiting of their distribution by low water levels (Rossa and Bonecker 2003; Bowers and de Szalay 2004. Meanwhile, indirect effects are generally through alteration of habitats (e.g. substrate composition, periphyton growth, resuspension versus sedimentation). Particularly important are those habitats with cobbles and macrophytes that provide an extensive suitable habitat for periphytic algae which are their major food source, egg-laying and tube building, and also provide a refuge from predation (Scheifhacken et al. 2007). However, different zooplankton groups seem to show different sensibility to water level and are distinctly affected by floods (Ortega-Mayagoitia et al. 2000).

Fishes are particularly susceptible to changes in environmental conditions. Flow plays a profound role in the lives of fish with critical life events linked to flow regime (see Bunn et al. 2002; Janáč et al. 2010). Numerous studies have shown that changes in stream flow associated with extreme variations in precipitation can alter fish communities and habitats. Many fish species display a preference for particular types of habitat such as pools, riffles, or backwater areas. While habitat structure is generally considered to be a good predictor of fish assemblage structure, so habitat instability associated with variations in stream flow will disturb the fish community residing within it (Gelwick et al. 2001). Therefore, sudden or long term variations in discharge, such as from extended droughts or large storms, can be particularly devastating, causing changes in water chemistry, stream size, water temperature, streambed structure, streambed substrate and stream flow (Medeiros and Maltchik 2001). Extreme discharge associated with storm events can dramatically alter channel morphology and benthic habitat, which may have significant effects on fish community. Such environmental alteration can dramatically alter the living conditions and aquatic habitats within the water, affecting much of the aquatic fauna inhabiting streams (Moyle and Vondracek 1985; Taylor and Warren 2001).

Crosa et al. (2009) reported that a large volume of sediment associated with reservoir flushing has decreased fish density and biomass; a greater mortality recorded for juveniles will likely result in long-term impairment of the age-structures fish populations. Juveniles' mortality was also reported due to flushing (Garric et al. 1990), while lower effect such as damage of gill epithelium was observed (Petz-Glechner et al. 2003). High level of sediment can cause mortality in fish (Newcombe and MacDonald 1991), in particular sensitive specimen (Lloyd 1987), whilst prolonged lower levels of suspended solids and turbidity is the cause of chronic sublethal effects, such as reduced weight since individuals are not able to feed efficiently (Sigler et al. 1984). Stream fish can become stranded on gravel bars or trapped in off-channel habitats during rapid flow decreases. Susceptibility to stranding is a function of behavioral response to changing flows, and this varies with species, body size, water temperature, time of year and day, substrate characteristics, and the rate of flow reductions (Bradford 1997). However, mature fish may be able to shift into temporarily suitable habitats to compensate for periodic reductions in the quality or availability of habitat (Bunt et al. 1999).

Many variables known to affect fish, including sediment load, pH, dissolved oxygen, and various nutrients, are frequently changed during increased flow associated with storm events (Winemiller et al. 2000, Ostrand and Wilde 2002). Winemiller et al. (2000) showed that diversity and abundance of freshwater fish populations positively correlate with total dissolved nitrogen, nutrient concentration, and food resources in the water. Gelwick et al. (2001) found positive correlations between common measures of assemblage structure (diversity and abundance) and dissolved oxygen and salinity. However, in other case, the degree of change in chemical composition observed was minor (Keaton et al. 2005).

On the other hand, extreme storm events that lead to flooding can introduce new species into assemblages and create new habitats (Winemiller et al. 2000), or increase availability of shelter and allochthonous food sources, and should provide water enrichment with nutrients carried from adjacent areas or present in flooded organic or inorganic material (Agostinho et al. 2004). Nevertheless, floods can dilute the aquatic biota by increasing water depth, reducing the availability of food resources, especially mobile ones. As a result, the hydrological cycle affect interspecific relations, particularly predation and competition. The flooding regime seems to favor piscivores, since floods are associated with the reproductive success of many of their prey species. However, due to their diluting effect, floods also reduce the density of prey species. In addition, increased shelter may also reduce prey availability (Luz-Agostinho et al. 2008; Janác et al. 2010).

DROUGHT AND FRESHWATER BIOTA

In contrast with the facts on flood effects, there have been relatively few studies of stream faunal dynamics after droughts (see Lake 2000). If floods amplify hydrological connectivity, conversely droughts in streams disrupt hydrological connectivity. With the onset of drought, falling water levels reduce the habitat availability for most aquatic biota, exposing the marginal areas (Stanley et al. 1997), breaking surface water contact between the stream and its riparian zone, and reducing the hydraulic heterogeneity of flow. Changing water levels are another stressor on lake and littoral communities. Water level fluctuations in lakes are dominant forces controlling the functioning of lacustrine ecosystems (Wilcox and Meeker 1992; Poff et al. 1997). It plays an important role in the lake's physical processes (e.g. the geomorphologic processes of erosion and sedimentation) (Leira and Cantonati 2008).With falling water levels, lentic habitats may increase in extent and new types of habitats may be created, that favor some species. As drying proceeds, the threshold of cessation of surface flow is reached.

Droughts can have direct and indirect impacts on stream biota. Direct impacts are those caused by loss of water and flow, and habitat reduction and reconfiguration, whereas indirect impacts are those associated with changes in phenomena such as interspecific interactions, especially predation and competition, and the nature of food resources. The direct and indirect impacts of drought can greatly reduce population densities, species richness and alter life-history schedules, species composition, patterns of abundance, type and strength of biotic interactions (predation and competition), food resources, trophic structure and ecosystem processes. Resh (1992) found that a severe drought has eliminated a population of the caddisfly, *Gumaga nigricula* (McL.).

Following water flow reduction, many aquatic biota cannot move and become trapped and concentrated in lingering pools (Boulton et al. 1992; Matthews 1998; Matthews and Marsh-Matthews 2003). Stream connectivity becomes differentially disrupted by the cessation of upstream-downstream longitudinal links, and the weakening of lateral links between the stream channel and riparian zone (this includes the flood plain) and vertical links between the surface, hyporheic zone and groundwater. In terms of available data on responses to drought in flowing waters, more information is available on invertebrates and fish than on micro-and macroalgae, macrophytes and riparian plants (e.g. Peterson 1996; Matthews 1998; Holmes 1999). During drought, flow may cease and some stretches of river consist of isolated pools, where biota become concentrated in pools and such pools may harbor very high densities of invertebrates (e.g. Boulton and Lake 1992; Miller and Golladay 1996) and of fish (e.g. Matthews 1998; Labbe and Fausch 2000; Matthews and Marsh-Matthews 2003). Different isolated pools may harbor different assemblages of biota and with time, such pools can diverge from each other in their community structure (Power et al. 1985; Meyerhoff and Lind 1987; Stanley et al. 1997). In reservoirs, during extreme drawdown events, the water quality changes significantly. In particular, drawdown events cause changes to nutrient dynamics and ultimately lead to periods of high algal biomass; in one case leading to the formation of a potentially toxic cyanobacterial bloom (Naselli-Flores 2003).

Physicochemical conditions shift rapidly with flow cessation and undoubtedly have adverse effects on the benthos. When flow decreases, the capacity of the stream to transport organic matter decreases and cause an increase in detritus coverage. Further, flow cessation lead to watercourse fragmentation into a series of isolated pools and caused an abrupt change in physicochemical conditions that imposed a threshold on the ecosystem (Acuna 2005). Organic matter or detritus and sediments are accumulated in pools, and reduce physical reaeration causing a decrease in DO concentrations and an increase in nutrient concentrations, typical responses to pool isolation (Stanley et al. 1997; Caruso 2002).

On the onset of drought, tolerant species can grow rapidly leading to a density peak soon after flow cessation, but this density peak dropped rapidly in response to changes caused by flow cessation (Boulton and Lake 1992). The most probable causes of these adverse effects are deoxygenation (Stanley et al. 1997; Labbe and Fausch 2000) and toxicity of certain leachates from leaf decomposition (Towns 1991; Boulton and Lake 1990, 1992; Chergui et al. 1997). As streams dry and the surface water shrinks to unshaded pools, the build-up of nutrients, high temperatures and solar radiation can precipitate blooms of algae (Freeman et al. 1994; Dahm et al. 2003; Winder et al. 2012). The algae may create large diel changes in oxygen concentration (Matthews 1998). As water flow and volumes decrease, water temperatures may start to rise (Acuna 2005) and can become lethal for aquatic biota such as fish (Matthews 1998). Simultaneously, especially in pools, deoxygenation may occur, threatening biota (Stanley et al. 1997; Labbe and Fausch 2000; Golladay et al. 2002).

Low discharge conditions during drought can limit habitat resources and mobility (Lohr and Fausch 1997) and can have marked effects on community composition, diversity, size structure of populations, spawning, and recruitment of fish (see Poff et al. 2001; Lake 2003; Ledger et al. 2012). Droughts also results in intense aggregations of fish and possible competition for food and/or space, because fish are confined to small areas and usually at considerably higher densities, thus potentially increasing competition. Poff and Ward (1989) considered that such biotic interactions contribute relatively little to community structure in rivers. However, during periods of low flow, and the attendant reduction of habitat area or volume, biotic interactions could become temporarily important (Cowx et al. 1984; Matthews 1988). Fish population structure can also be changed by drought (Resh et al. 2013), reducing spawning and recruitment (Cowx et al. 1984; Davies et al. 1988). Pires et al. (1999) note that some species are well adapted to natural droughts, however major native species are considered to be more sensitive to stream fragmentation and hydrological alteration (Parkin et al. 2014). In addition, habitat degradation and possibly the introduction of exotic species contribute to marked variability in species composition. Meanwhile, droughts may raise water temperature and reduce dissolved oxygen, imposing adverse physical conditions on fish in the pools.

CONCLUDING REMARKS

Research have regarded that tropical areas are expected to suffer more severe impacts of climate change, from heavy floods or extended drought. Such extreme fluctuation of water flow will, to some extent, threat the performance of tropical freshwater biota. Floods and drought can negatively affect the biota, both directly and indirectly, through the changing environment. Research suggested that the magnitude of hydrological changes may be acute to species, disturb reproduction or succession, change the distribution, and lastly restructure the biotic communities in rivers, streams, floodplain, ponds, and lakes.

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