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Review Article

Plankton Diversity, Physico-Chemical Parameters and Conservation Value of Temporary Freshwater Rock Pools

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ABSTRACT

Rock pools occur everywhere in the world and are geo-morphologically similar because they originated from weathering and erosion although vary in surface and depth. Interestingly, rare species are found as rock pool communities, which have never been recorded from open water. Temporary fresh water support invertebrate communities ranging from the complex, with many species to those that support only one or two species. The high variability in environmental condition connected with relatively unpredicted flooding regime limit for specialized species with high tolerance to stress and specific feature for surviving the dry phase. The differences in number of rocks and pools together with sampling intensity of individual pool may probably explain part of the variation in recorded diversity. Indeed, it is an established fact that the rock pools biotas are fully dependent on length and abundance of inundation and for that, the active communities will reflect the current climatic conditions. Temperature, Dissolved oxygen and pH are vital to the survival of many temporary water species as it provides essential indications that regulate the timing of life cycles, flight periodicities and colonization dynamics. Freshwater ecosystem served as an important asset for man and habitation for an extraordinary rich, endemic and sensitive species. Increase in human demand on these ecosystems results to large and rising threats to biodiversity and for that recording diminishes of biodiversity, identifying their causes, and finding solutions have become necessity in freshwater ecosystem.

Keywords: Plankton, diversity, conservation and freshwater rock pools.

INTRODUCTION

Temporary fresh water support invertebrate communities ranging from the complex habitat, with many species (e.g., vernal ponds), to those that support only one or two species (such as ephemeral rock pools and water-filled leaf axils) predators in rock pools which colonize pools after inundation. Previous researches on freshwater rock pools concentrate on general species of macro and micro flora and fauna in and riparian of rock pools. [1-7] The aim of paper is to provide critical review on freshwater rock pools with emphasis on characteristic, essential role of the water physico-chemical parameters on planktonic community and conservation value.

Temporary freshwater rock pools characteristics: Freshwater rock pools (a group of all types of depressions that occur on rocky substrate and periodically hold water) which are found all over the world in all major biomes depends mainly on precipitation for filling. The hydro periods ranging from several days to a whole year and interaction between the climate and geology determined the morphology and hydrology of this habitat. [4] It experiences daily changes of water temperature, pH and CO2. [1] They have low conductivity and wide range variation of pH (from 4.0-11.00) and temperature from freezing point to 40°C. The uncertain nature of the flooding regime requires high endurable species with adaptation for surviving the dry phase such as resistance stages, active emigration followed by re-colonization. About 460 animal species are recorded from rock pools worldwide and 170 of these are passive dispersers, that is, those mainly dispersed by wind and the overflow of water between the pools. Freshwater rock pools stand as a source of freshwater in dry countries, but despite that, they remain unexplored in large parts of the world. [4]

In most cases, freshwater rock pools are temporary waters. The freshwater rock pools are characterized by highly unpredictable in timing and length of the inundation period. [8,9] The hydro-period in rock pools averagely ranged from several days up to a month [9] and several months in the case of semi-permanent rock pool [4]. Rock pools occur everywhere in the world and possess very similar structure and abiotic environment. They are geo-morphologically similar because they originated from weathering and erosion [10,11] although vary in surface and depth. Weathering and erosion may result to joining of neighboring pools that may lead to more complex shape. [12] Rock pools are usually in the form of pan, or bucket shape with a cylindrical or ellipsoid surface and different in dimension. [12]

Like other types of temporary water habitat, rock pools fauna are categorized into two, namely: permanently resides (as resistant life stages) and migrates (when pools are dry). [13] The high variability in environmental condition connected with relatively unpredicted flooding regime limit for specialized species with high tolerance to stress and specific feature for surviving the dry phase. Most pool biota survives the desiccation through resting stages such as dormant eggs, resistance larvae or by active migration and re-colonization. [13,14]

Hydro-period, is so important to the extent of determining the composition, structure and diversity of the rock pool bio-community. [15] The climatic change in rock pool significantly changes the hydro-regime with decreasing stability on some biotas. This established the hydrologic sensitivity of rock pool habitats to precipitation patterns and its potential to predict future climatic change. The regularity and duration of inundation depend on basin physical factor (shape, size and structure), area, types of vegetation and local climate. The maximum depth of basin determines the maximum length of inundation period. [16] Rock pool mostly filled with rain water, which results in the highly diluted environment at the beginning of the inundation. The conductivities of this water are below 10 µScm-1 and varying depth ranging from 5cm to 30cm. The temperature of the water, close to the air temperature and show wide diurnal fluctuation in pH and dissolve oxygen. The freshwater rock pool is distinct between the pool filled by precipitation and those fed by rivers and ground water. The ground water fed rock pool (e.g. quarry pond) and potholes in the river floodplains inhabit biotas that are mainly brought in with the water. These communities of fauna in these habitats are not often adapted to this temporary pool condition. However, the precipitation dependent rock pools accommodate communities of species fit to survive dynamic and unpredicted flooding cycles.

Unlike other temporary pools that are characterized as an enemy-free habitat [17,18] predation is an essential component of rock pools and considered to be an essential community structuring factor. Examples of such predators are clawed toad, Turbellaria, notonectids, odonates and ceratopogonid midge larvae. [16,19-21] Jock *et al.*, 2010 [4] mentioned water mite as common.

Plankton communities in rock pool: Previous studies reveal that rare species are found as rock pool communities, which have never been recorded from open water. [22,23] Such rock pool species possess physiological or behavioral features that can help population persistence in the pool. [23,24] The plankton community in rock pool may be used as a model system to study many ecological concepts such as community assembly, spatial population dynamic and local extinction. [25] Planktonic community composition differs spatially between pools and temporarily within the same pools. [26] Occurrence or absence of some phytoplankton species in a pool depends on arbitrary dispersal of propagules by wind or animals. [27-29] Physico-chemical circumstances and biotic interactions during each wet season determine establishment and maintenance of sustainable populations. [27,29,30] McLachlan, 1985 [31] revealed that most of algae insect larvae and tadpoles colonize small temporary rain–filled rock pools in Malawi.

Phytoplankton rapidly grows in temporary rock pools. This comes from inocula, which are readily dispersed as dry cysts or spores by wind. [32,33] Frequency of the heavy rainfall followed by storms may result to the pools flushed out so rapidly that algal populations do not have time to form. [33] Nevertheless, motile algal species like Euglena and Chlamydomonas species use their flagella to remain suspended in the pool, can withstand being flushed out.

Nitrogen and phosphorus are major inorganic nutrients required by phytoplankton. The phosphorus limited algal growth, but stimulates algal productivity and enhances eutrophication processes when in excess. [34,35] In surface water, nitrate is the nutrient taken up by algae, assimilated into cell protein. Nitrate is relatively a soluble ion and usually available in water, though it may limit algal growth at times. [33] The productivity of any aquatic environment depends on the phytoplankton and the environmental conditions that affect them. The factors that influence phytoplankton growth in ephemeral rock pools are variations in water chemistry, irradiance, nutrient supply, and presence of tadpoles, temperature and the washout rate. [33,36] Reynolds (1986) [37] also reveals that disparity in the chemical composition of natural waters might be significant in regulating the diversity, density and the geographical and periodic distribution of phytoplankton. Though the ephemeral nature of the pools excludes some organisms such that only organisms that can aestivate, survive desiccation and have very fast rates of development during the inundation phase can live in these environments [38] or produces resistant eggs or are themselves able to enter a resistance, resting stage [13,39] and a majority of their life span may depend in these diapause stages. [40]

The zooplankton in second level, transform food energy synthesized by the phytoplankton to the higher tropic level. [41] Economically, zooplankters are the major primary consumer or intermediate of energy transfer between phytoplankton and other aquatic animals including fish. [42-44] Moreover, zooplankton is the most vital biotic components affecting mostly the functional aspects of all aquatic ecosystems, via; food chains, food webs, energy flow/transfer and cycling of matter. Different environmental factors that detect the features of water play essential role on the growth and abundance of zooplankton. [45] As such, water quality influences zooplankton abundance, clustering and biomass. Four major groups of zooplankton (protozoans, rotifers, cladocerans and copepods) dominate the temporary freshwater rock pools. [46,38] The pools give lodging to large branchiopod crustaceans. [3,20] Many branchiopod species can withstand oxygen concentration of less than 5mgl-1. Virtually all cladocerans species survive at a pH ranging from 6.5 to 8.5. [47] One of the major invertebrate predators in temporal pools on rock substrate is turbellarians. The presence of the turbellarians in large densities, diminish the zooplankton densities drastically and may lead to total extinction of the active population. [48] Predation of zooplankters by both amphibians and several invertebrates may be a vital biotic mechanism regulating temporary pool communities. [38,46,48,49]

Physico-chemical parameters: Water quality characteristics of freshwater rock pools assessed from different studies are presented in Table 1. The generally small volume of sandstone and granite rock pools results in a low buffering capacity, with marked changes of physical and chemical variables over short time scales often in a daily cycle. [50] Rock pools are characterized by low conductivity immediately after filling, typically fluctuating between 10 and 30 µScm-1. As the water evaporates, conductivity increases mainly because of the concentration of metabolites and can reach values up to 1400 µScm-1 in pools with the longest hydroperiod (Table 1).

Water temperature affects water physico-chemical factors such as dissolved oxygen concentration, pH and primary production. Water temperatures closely follow the ambient air temperature due to shallow nature of most rock pools; hence show high diurnal variations. [51] Temperature is vital to the survival of many temporary water species as it provides essential indications that regulate the timing of life cycles, emergence from and entry into diapause, flight periodicities and colonization dynamics. [52] According to Alhassan & Hazel (2015) [53] noted that water temperature in rock pools depends on climate whilst, maxima varies from 29°C in Malaysia. On a similar noted, it was 32°C in Finland [54] 34°C in Zimbabwe, [55] 35°C in Utah [50] and above 40°C in Botswana. [9] Water temperature rarely exceeds 40°C due to the balance between cooling through evaporation and heating by insolation. The physico-chemical features of temporary waters strongly influence the bio-communities present, but biological factors may be vital as well, especially with increased duration of the hydroperiod. Temperature is a very important environmental variable that fluctuates seasonally, daily, or even hourly basis. The typical shallow nature of temporary water rock pools highly subjected than rapid heating from solar radiation, cooling at night and also from wind. Thus, temperature inversions, together with kinetic energy transfer from wind blowing over the water surface, put the water column in motion, as a result stirs up bottom materials. The annual temperature regime recorded in Utah revealed an increase from a post-snowmelt value of around 4.0°C to a maximum of 35.0°C in mid-summer. [4] However, some temporary water bodies experience a daily temperature turnover similar to that seen annually in permanent lakes. [56] The biological implications of such type of shortterm temperature changes are not clearly understood.

Dissolved oxygen also follows the same pattern with temperature of a strong daily and seasonal cycle. A study with dissolved oxygen concentrations in fluctuation range 5.8 and 7.9 mg L-1 [51] averagely over eight pools measured during 8 days in South Africa. Little Variation in oxygen concentration over a complete inundation cycle was revealed between pools, though, ranging in one study from 3.5 to 9.6 mg L-1. [51] This shows that variability is greater in other systems. Dissolved oxygen in temporary rock pools waters may fluctuate diurnally as a result of photosynthesis and respiration. Whitney (1942) [57] discovered that, oxygen pulse to be at a maximum immediately after dark, when the day's photosynthesis had done, but thereafter it fell slowly due to overnight respiration. This observation made him conclude that, absorption of oxygen from the air was of quite less importance, as often absorption values were far below the air saturation value for a particular temperature. Additionally, the oxygen content of the water frequently changed during a period when a uniform temperature prevailed. Schneller, (1955) [58] found that during the low flow stages of Salt Creek, Indiana, large quantities of decaying leaf matter were sufficient to cause an oxygen depletion combined with an increase in free carbon dioxide from the activities of decomposers.

The rock pools water pH ranges from acid (pH = 4.3) to alkaline (pH = 11.3). The macrophytics and phytoplankton produces carbon-dioxide in the night during respiration which resulted to decreasing in pH of water in early morning [59,60] found that in many small ponds in Europe, the amount of diurnal photosynthesis could totally exhaust all of the available carbon dioxide. pH may increase as a result of this exhaustion, although the degree of pH change would depend not only on the intensity of the photosynthesis, but also on the magnitude of buffering available, alkaline soils from surrounding can be used as an example. Moreover, in various temporary waters, oxygen levels depleted rapidly after inundation, as basin sediments and soils become flooded. Renewed microbial activity removes the oxygen, creating a reduced redox state in the bed. [61]

Up to 1.5 units of variation was observed in a diurnal cycle, [50] pH variation affects alga growth in many ways. It changes carbon-dioxide, species and carbon availability and distribution alter the available trace metals and important nutrient, and the very high pH level lead to direct physiological effects. Freshwater studies revealed that species succession is determined by the ability of certain species to proliferate at high pH presumably due to their tolerance of low CO2 levels. [62-64] The pH of rain, almost everywhere in the world is lower than 5.6 and the factors that are responsible for acid deposition or acid rain are sulfur dioxide (SO2) and nitrogen oxides (NOX). [65]

The pH of water in freshwater and other aquatic ecosystem, are very essential to aquatic communities because it regulates the exchange of respiratory gasses and salts with the water which they live. Inability to regulate these processes can lead to diminished growth rate and even mortal in case of high pH above the range that can be tolerated physiologically by aquatic organisms. [66] The pH affects normal physiological processes of freshwater communities such as the exchange of ions with the water and respiration. This physiological process usually functions well in aquatic biotas under a relative pH range of 6 -9 unit. [67-69] In freshwater with healthy and diverse macro invertebrate, the pH was observed to be approximately 6.5 - 8.2 units. [70-73] Similar was also observed in temporary rock pools with approximately 6.1 - 8.2 Units [53] some species of algae were reported to live and survived at pH 2 and lower, and some at pH 10 and higher. This revealed that, there is no defined pH range specific to all freshwater communities. [67-69] The acceptable range of pH to aquatic communities depends on prior acclimatization, water temperature, dissolved oxygen concentration and the concentration and ratio of cation and anions. [70]

Diversity in rock pools: The phytoplankton and zooplankton species diversity and density in rock pools varies considerably among studies. It is a common agreement that diversity increases stability in communities and ecosystem. [74] Alhassan & Hazel (2015) [53] study in Upeh Guling, Malaysia and reported 122 species of phytoplankton and 49 species of zooplankton (Table 1). The plankton was collected six times within a year from 4 rock pools. Based on the study conducted by, [55] 25 species of phytoplankton and 20 species of zooplankton were recorded based on weekly sampling from 20 rock pools. On the other hand, previous researchers who studies invertebrates but did not include phytoplankton are [75] with a 66 species of invertebrate recorded from 92 pools on two outcrops among which zooplankton were 47species representing 71.21%. Similarly, 230 species of aquatic invertebrate were recorded from 90 pools equally divided in 9 different outcrops where 71 representing 30.87% zooplankton species were recorded [76] Bayly (1997) [77] research recorded 88 species of invertebrate in 36 rock pools on 17 granite outcrops. The study recorded 31 species of zooplankton representing 35.22% from the total number of invertebrates recorded (refer to Table 2). Rock pools inhabited remarkable high diversity of passive disperser when compared with other temporary water bodies like phytotelmata (water held in plant). This may be attributed to temporary stability and physical properties of the habitats together with the low exchange rate of individual species between cluster habitats usually isolated from different outcrop. The differences in number of rocks and pools together with sampling intensity of individual pool may probably explain part of the variation in recorded diversity.

Table 1: Comparison between planktonic communities of rock pools records from previous finding

AUTHOR/YEAR	ROTIFERS	CLADOCERANS	COPEPODS	Total
Bayly, 1997	-	24	7	31
Pinder et al., 2000	23	36	12	71
Jocque, 2007	42	3	2	47
Tavernini, 2008	41	5	8	53
Anusa, 2012	8	5	7	20
Alhassan & Hazel, 2015	35	12	2	49

Table 2: Comparison between planktonic communities of rock pools records from previous finding

AUTHOR/YEAR	Anusa*et al.*, 2012	Alhassan & Hazel, 2015
Blue green algae	1	8
Green algae	19	60
Yellow algae	-	2
Golden brown algae	-	2
Diatoms	1	39
Cryptomonads	-	2
Euglenoids	2	5
Dinoflagellates	2	4
Total	25	122

Indeed, it is an established fact that the rock pools biota is fully dependent on length and abundance of inundation and for that, the active communities will reflect the current climatic conditions. [4] The rock pool communities thus may be fit as proper monitoring system for identifying environmental changes on both short and long time basis and learning the climatic changes effect on bio communities. The rock pools habitat is unique for accommodating specialized and endemic species and therefore contribute essentially to regional diversity. [75] Manson (2000) [78] stated that establishment of conservation strategies may not be straight forward in fresh water habitat but protection of this habitat is essential.

Freshwater conservation: Freshwater ecosystem served as an important asset for man and habitation for an extraordinary rich, endemic and sensitive species. Increase in human demand on these ecosystems results to large and rising threats to biodiversity everywhere in the world. Due to these emerging threats around the world, recording diminishes of biodiversity, identifying their causes, and finding solutions have become necessity in freshwater ecosystem. Freshwater covers only 0.8% of the earth's surface, yet it sustains not less than 100,000 species, which represents 6% of all known species on earth out of a total of 1.8 million species by approximation. [79,80] The typical inhabitant of temporary habitats crustaceans, molluscs, rotifers, cladocerans, tardigrades, turbellarians and hydrozoans and survived the habitat by produces resistant eggs and sometimes they are able to enter a resistance and resting stage [35,13].Previous sstudies revealed that loss of temporary freshwater pool habitat range from 90% - 97% in California. [81] According to Holland (1978); Stone (1990), [82,83] temporary freshwater pools at a time covered 1/3 of the central valley, along the perimeter of the foothills and down the middle of the valley. However, farm activities on top of rich soil, expansion of urban areas due to increase in population lead to the increased destruction rate of the temporary freshwater habitats.

Phytoplankton serve as food for aquatic organism, produces oxygen for hydrosphere and atmosphere, also used for biofuel, industrial use for drugs and Bioremediation while zooplankton served as food for higher aquatic animals, live food for aquarium and aquaculture industry and contribute in water quality. Christopher (2008) [84] revealed that phytoplankton (Algae) are use as bio-filters for removal of nutrient and other pollutants from wastewaters, to examine water quality, as indicators of environmental changes, in space technology, and laboratory research system. They are cultivated for the purpose of pharmaceuticals, nutraceuticals, cosmetics and aquaculture. These vital contributions of plankton to human and the entire world made it necessary for their conservation. Millar and Kraft (1993) [85] and Millar (2003) [86] first documented the case of extinction of an alga (Vanvoorstia bennettiana (Harvey) Papenfuss (Delesseriaceae, Rhodophyta) in history. Watanabe *et al*., (2005) [87] reported the endangered of 24 charophycean taxa to which some may now be extinct. According to Simovich (2005), [88] temporary freshwater pools surveys in California revealed that 50% the habitat crustaceans are yet to be described and about 30% of these species have gone extinction before being discovered. [89] The causes of species extinct in freshwater may be the threats of habitat destruction and degradation. To reduce the rate of loss and extinction of species is by creation of artificial pools or conservation of the natural habitat that are in place. Although little evidence revealed that artificial habitat can support the diversity of natural pools. [89] It has become necessary that the little remaining habitat should be studied and understood for appropriate protection. Brodie *et al*., (2009), [90] suggested that the species conservation will be achieved by protection of the habitat or organisms. Many scientists prefer protection of habitat and allowing the organisms of that community to adapt themselves to the environmental factors of the habitat. The vital role played by fresh water rock pools in housing endemic and rare species of plankton and the benefits of these species to other organism necessitate their conservation in ecosystem.

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