Aquatic Temperature and its Ecological Systems: A Review of Knowledge and Approaches for Studying Aqua-biota Responses

Abstract

Available studies directing to aquatic temperature in Niger Delta aquatic ecological systems was carefully studied and developed as a review that takes on the tempo-spatial variation in that systems, the essence of being knowledgeable in facts relating to aquatic temperature of ecological systems, the vital points in the development of aquatic temperature modelling through its measurement, anthropogenic agenda that modify the aquatic temperature, the impact of temperature changes on the physico-chemical parameters of aquatic system; and on aqua-biota. Various ways of assessing the impacts of temperature variations in aqua-biota are spelled out and aquatic temperature criteria for the protection of aqua-biota are detailed. This review paper beams on the complexity of aquatic temperature in the ecological system; the need of being knowledgeable in tempo-spatial variability, the various responses of aqua-biota to temperature thermal stress; the anthropogenic agenda that modified the aquatic temperature and the current threat to aquatic ecology systems the climate change.

Keywords: Aquatic temperature, aqua-biota, aquatic ecological systems, anthropogenic agenda, modelling

Introduction

Naturally, thermal properties of aquatic ecological systems are based on some salient factors, which include regional (attitude, latitude); structural (water depth, substratum, morphology, turbidity, topographic features, vegetation, channel); climatic (temperature, solar radiation, cloud cover, wind direction, wind speed, precipitation, evaporation, vapour pressure); and hydrological (tributaries, water volume, discharge, source of water and relative contribution of groundwater) of the area, site and catchment (Fig.1) (Dallas, 2007). The focal point of these features varies amongst aquatic system.

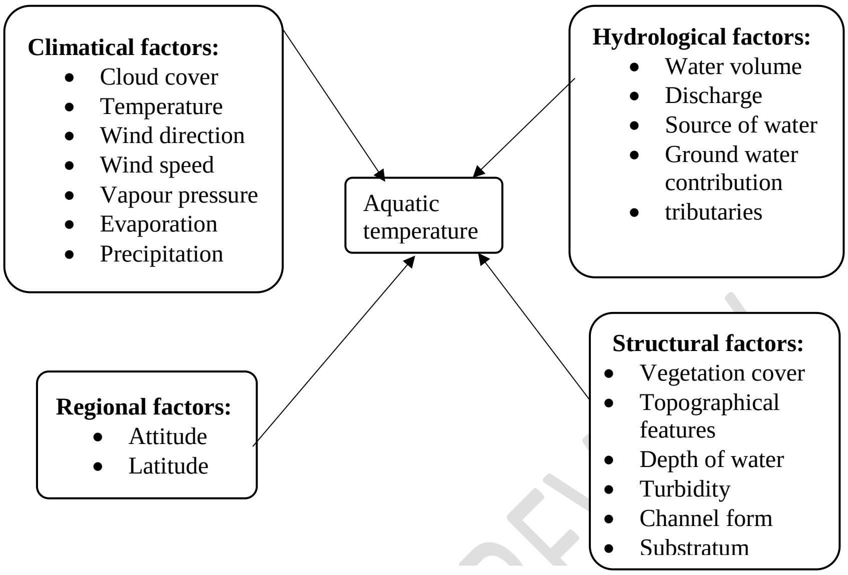


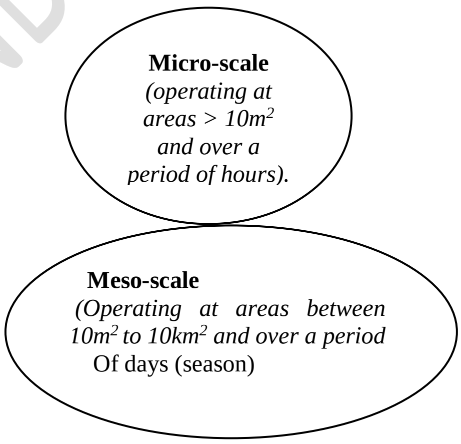
Fig. 1: Factors affecting aquatic temperature in ecological systems (Dallas, ~~2008~~2007.

Tempo-Spatial Changes in Aquatic Temperature

Considering the catchment scale, changes are piloted by difference in some ecological factors (Pool *et al.*, 2001), while difference take place longitudinally down on aquatic system, especially river course having the head waters cooler than lowland areas, at the river scale. Maximum temperatures often increase downstream, but the maximum range is usually observed in the middle reaches (Dallas and Rivers-Moore, 2008; Thomas *et al*., 2013.

At the site scale, variations are usually ascertained by changes prompted by geomorphological features (Ebersole *et al.*, 2003, Pool, *et al.*, 2001), with various habitats showcasing varied temperature regime (Dallas and Rivers-Moore, 2008).

In running aquatic systems (lotic water), temperature periodicity patterns had been observed to be on hourly, daily and seasonal basis and also with respect to the nature and size of the systems (Dallas and Rivers-Moore, 2008, Dallas, 2007; Poole *et al.*, 2001; Macaraeg *et al.*, 2023). The duo combination of tempo-spatial changes in temperature, birthed three major tempo-spatial scales namely: micro-scale; meso-scale and macro-scale. These scales type are used on different time period (Fig.II) (Dallas, 2008, Poole *et al.*, 2001). The in-depth knowledge of trends and changes in tempo-spatial temperature of aquatic ecological systems is very significant in prompting the understanding of bio-ecological responses to variations in system. This will aid in studying and also assessing such systems (Arscott *et al.*, 2001). Studies of aquatic temperature as a key environmental variable scripting aquatic habitat in Niger Delta Region of Nigeria have been noted and this include tempo-spatial changes (Balogun and Onokerhorage, 2002; Braide *et al.*, 2013; Ikehi and Zimoghen, 2015; Akpan *et al.*, 2023).



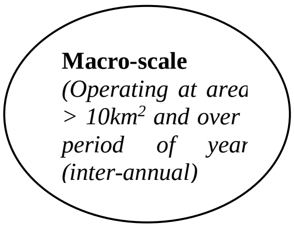


Fig.II: Combined ~~spatio~~spatial-temporal temperature changes scale (Guderson, *et al.*, 1995) In: Rivers Moore *and* Jewitt, 2004)

The Significant of Aquatic Temperature in the Ecological Systems

The significant of aquatic temperature in the ecological systems had been studied by various scientists (Cassie, 2006; Dallas and Rivers-Moore, 2008; Akpan *et al.*, (2023); Akpan and Etim, 2015;~~,~~ Akpan (2013);~~,~~ Akpan (2021);~~,~~ Ekpo *et al.*, 2012;~~,~~ Essien-Ibok *et al.*, (2010).

Previous studies focused on thermal pollution and its attendant effects in the aquatic ecological system (Dallas and Rivers-Moore, 2008; Abidi *et al.*, 2022; Dugdale *et al.*, 2017) but nowadays, the potential drive of climate change on aquatic ecological system is the main research focus. This research with its experimental design has a broad base ideology, including knowledge on thermal regime, developing nov~~a~~el scope like temperature modelling, documentation of anthropogenic agenda which stemmed up thermal variations and the ecological impacts of these variations; and initiating modules for assessing and estimation of thermal tolerance ranges, using field and laboratory experiment. In some part of Europe and North America, the study of thermal characteristics is immense and well recorded (Ward, 1985 In: Dallas, 2007) and are considered vital in either positively or negatively influencing biology of aquatic species. In African region, thermal data is dearth and most information are derived from eco-hydrobiological studies (Appleton, 1976 In: Dallas, 2007), based on aquatic temperature (Rivers-Moore and Jewett, 2004; Rivers-Moore *et al.,* 2005; 2006). An established argument exists on the validity of eco-concepts developed in the aquatic system, especially on rivers of different parts of the world (Lak *et al.,* 1985 In: Dallas, 2007) and it has been opined that environmental variability is a major factor in the eco-concept development (Mckie *et al.,* 2004).

Determination of Aquatic Temperature in Aqua-Ecosystem-Insitu Determination

Researches on determination of aquatic temperature either used aquatic temperature loggers (this determines aquatic temperature on hourly periodicity) or record instantaneous measurements at various periods of the day. Viewing from the ecological aspect, the usage of aquatic temperature loggers is of great significant as it gives details on decimal differences, which is vital in ecological studies as it gives room for the assessment and determination of extreme aquatic temperature (Dallas, 2007). Aquatic temperature has been routinely studied in Niger Delta Region of Nigeria (Akpan *et al.,* 2022), Akpabio *et al.,* 2001, Atuma *et al.,* 2023, Wali *et al.,* 2020, Ebuete & Ebuete, 2018), this allows for prompt knowledge of wider trends in aquatic temperature, but does not enhance detail knowledge on decimal differences. Several studies have generated aquatic temperature data for many rivers in the Niger Delta Region; whuo stream in Port

Harcourt (Edori *et al.,* 2021), kolo river in Bayelsa (Ebuete and Ebuete, 2018), Andoni river (Komi and Sikoki, 2013), Okpoka creek (Abowei and George, 2009); Calabar river (Akpan, 2000); Upper Nun River (Kwen *et al.*, 2014), Etim Ekpo River (Akpan *et al.,* 2023).

Aquatic Temperature Modelling and its Important

Various researches championing on aquatic temperature models have been carried out, (Ahmadi-Nedushan *et al.*, 2007; Benyahya *et al.*, 2007; Dammo *et al.*, 2016, Dammo *et al.*, 2015, Igweze *et al.*, 2014, Ugbebor ~~(~~2019~~)~~, Agumagu and Todel, 2015 and Adamu and Abdu, 2012) and is effectively~~enhancely~~ sectioned into three groups: Deterministic, regression and stochastic models (Cassie, 2006; Erickson and Stefan, 2000; Adamu and Abdu, 2012; Webb *et al.*, 2003;~~,~~ Rivers-Moore *et al.*, 2005). This subject is widely reviewed by various authors (Cassie, 2006, Benyahya *et al.*, 2007) due to the sensitivity of the subject.

The stochastic and deterministic models are noted to be the most realistic models (Dallas and Rivers-Moore, 2008 and Benyahya *et al.*, 2007) with a great data intensive input. Aquatic temperature models enable data provision employ in the construction of thermographs for aquatic systems assessment, (Rivers-Moore *et al.,* 2005), with the derivation of two outputs (i.e., duration curves and degree curves), which enhance the sites comparison and quantification of cumulative warmth at a site within a season (Essig, 1998 cited by Rivers-Moore *et al.,* 2005).

Due to eco-importance of aquatic temperature and the potential impact of anthropogenic agenda on such, it is pertinent to provide aquatic resources managers with an efficient assessment procedure and modelling tools (Benyahya *et al.*, 2007). Aquatic temperature model plays a significant role in the temperature simulation, which could be applied to study the potential impact of anthropogenic effects on the thermal regime of aquatic systems, which include but not limited to decision support systems to assist managers in establishing optimum outflows that maintain adequate temperature ranges for aqua-biota (Krause *et al.*, 2005). The application of statistical models to determine or to estimate aquatic temperature is becoming a vital tool in aquatic resources and its habitat management (Benyahya *et al.*, 2007, Gobo *et al.*, 2014).

Anthropogenic Agenda and Modification of Aquatic Temperature

Various agenda developed by human in the quest of industrialization have been noted as leading causes in the modification of aquatic temperature, which usually prompt a shift in the aquatic temperature distribution with its attendant increase or decrease in its extremes; or a variation in the temperature difference (Table 1).

Table 1-: Anthropogenic Agenda and Modification of Aquatic Temperature

Agenda	Effects on aquatic Biodiversity and Ecological System
Aquatic flow regulation	In the natural aquatic system, its temperature increases as discharge decreases (Webb *et al.*, 2003), just as the rate of decimal change is inversely proportional to its flow rate, (Dallas and Rivers-Moore, 2008). Any deviation in the rate of

	discharge would likely affect the thermal capacity of an aquatic system and may prompt a higher water maxima and lower minima. Impoundments have been noted by scientist as a factor that altered the downstream biodiversity (Ogbeibu and Oribhabor, 2002). Generally aquatic flow regulation or flow modification or water withdrawal exert an input of the spatio-temporal variability of aquatic temperature (Sinokof and Gulliver, 2000, Abam (2001).
Thermal discharges and natural thermal characteristics	Thermal discharges to the aquatic system emanated from different sources viz; cooling waters from power generating stations, industrial discharges and irrigation waters (Ovuru and Dambo, 2003). These are accompanied with varied effects (Ovuru and Dambo, 2003); which are seasonal dependent; and also, on the extent of the mixture of the heated effluent with the receiving aquatic system (Abidi *et al.,* 2022). Heated effluent discharges to the aquatic system are connected to other kinds of pollution and its toxicity elevated when released with increased temperature. Natural thermal characteristics of aquatic ecological system are dependent on hydrological, regional, climatological and structural features of the area. In Niger Delta Region of Nigeria, the thermal state of its basin is limitedly documented (Akpabio *et al.,* 2013; Olumodu and Mode (2016) Ahiarakwem *et al.,* 2013).
Aspect of riparian vegetation modification	Aquatic temperature is influenced by riparian vegetation, this plant adsorbed incoming radiation, emit long wave radiation, which in turn affect evaporation, conduction and aquatic temperature (Collier and Smitt, 2000, Dallas, 2007). The eradication of this plant, exposes the aquatic system to direct solar radiation, which invariably prompt higher temperatures.

	This effect is highly experienced in the small streams than the large rivers (Dallas, ~~2008~~2007). Riparian vegetation influences air temperature, which play a significant role in the insect diversity (Snaddon *et al.,* 2000). Studies in the riparian vegetation on aquatic habitat in Niger Delta has been discussed by various scientists (Essien, 2012; Koskey *et al.*, 2021; Chinedu *et al.*, 2016; Owuteaka, 2016; Akpabio *et al.*, 2013; Phil-Eze and Okoro, 2008).
Aspect of global warming via climate change	Most anthropogenic factors which contribute to global warming as a consequence of climate change have been extensively reviewed by various authors, (Akpoilih and Okeanyanwu (2010), (Odjugo, 2010; Olaniyi *et al.*, 2011; Okon *et al.,* 2021; Elenwo and Akankali (2014), Bariweni *et al.*, 2012, Balogun *et al.*, 2022, Uyigue and Agho (2007), Sumaila *et al.*, 2011, Thompson *et al.,* 2021, 2017 and Udo and Akpan (2019), Ayuba (2012). The Niger Delta Region in Nigeria is vulnerable to issues of climate change due to intensive anthropogenic agenda frequently occurring in the region (CPED, 2019) Olaniyi *et al.*, 2011, Balogun and Onokerhoraye (2022). Studies have noted the impact of climate change in the Niger Delta region, to include sea-level rise, flooding, extreme weather events, less of wetlands and biodiversity, erosion, soil degradation, scarcity of water, destruction of infrastructure and built environment (Okon *et al.,* 2021; Odjugo, 2010, ~~and~~ Olaniyi *et al.*, 2011, and Ipinjolu *et al.*, 2014). Elenwo and Akankali (2014) noted that climate change affects the aquatic biodiversity, which cause the biota to either modify their body structure and function so as to tolerate the change in

	climate, migrate to new and comfortable habitat or even stand the risk of extinction. Ikehi and Zimoghen (2015) observed that the changing conditions in water bodies of the Niger Delta has caused the fish to move to different part of the water body, thus laboring fishermen to travel long distance for fishing. The climate change agenda also threaten fisheries immensely (Akpoilih and Ekeanyanwu, 2010, Akpan *et al.*, 2022, and Akpan *et al.*, 2022).

Generally, the range of distribution of some aquatic biota (Example, fish), which are sensitive to more thermal nature, could be modified due to increase aquatic temperature (Dallas, 2007, Akpoilih and Ekeanyanwu, 2010 and Elenwo and Akankali, 2014) and potentially reducing their distribution. This may have severe consequences for various aquatic species, which are already under pressure from anthropogenic agenda, as observed in the Niger Delta Region (Akpoilih and Ekeanyanwu, 2018).

Classification of Aqua-Biota and Temperature Effect

Aquatic biota is basically classified into (a) warm stenotherm, i.e. those biotas with narrow tolerance ranges in warm regions of the world, e.g. tropics (b) eurytherms; i.e. those biotas with wide tolerance ranges, e.g. in temperate or sub-tropical regions and (c) cold stenotherm; i.e. biota with narrow tolerance ranges e.g. cold artic regions of the word. (Langfond, 1990 in Dallas, ~~2008~~2007). Aquatic temperature influence may be observed at the individual stage through physio-behavioural influences; population stage by biota development (reproduction and life histories) and community stage through functional and modification of structures.

Physio-behavioral Responses of Aqua-biota to Temperature

Aqua biota which are ectothermic are very susceptible to any deviation in aquatic temperature (Ogbone *et al.,* 2015), due to the fact that such deviation could pumps up the metabolic rate of the biota (Dallas, 2008). The elevated respi-oxygen demand, in combination with reduction of such supply provokes a significant stress to the aqua biota (Dallas, ~~2008~~2007). The rate of metabolism of biota usually increases in response to elevated aquatic temperature (Amekwe and Ebonje, 2008).

Studies on bacteria and diseases in the aquatic habitat have shown that the prevalence of the bacterial diseases, fish tuberculosis caused by *Mycobacterium marinum* increased from 5% to 15% in fish populations in the Niger Delta when water temperature increased by 2^0C (Opara and Anukwe, 2009). Water temperature plays a key role in the increase and prevalence of parasitic infection in fish. Studies have shown that the prevalence and intensity of infection with *Gyrodactylus africanus* increases with temperature (Opara and Anukwe, 2008).

The behavioural response to temperature on ectotherm species is Niger Delta waters is complex and varies (Ogbone and Ajayi, 2015). In the region, the temperature varies with respect to time of the year and location (Akpan, *et al.*, 2023). At wet season, temperature is high and humid (Ogbone *et al.*, 2015), however cooler and drier at dry season. These changes pose a vital impact on the behavioural pattern of the ectotherms (Ogbone *et al.,* 2015). Nile crocodiles are ectothermic reptiles that are found in the Niger Delta Rivers (Huey and Kingsolver, 2019). During the hot season, Nile crocodiles tend to be more lethargic and spend more time in the water. They may also become more nocturnal. During the cooler season, Nile crocodiles become more active and may spend more time basking in the sun. African lungfish are ectothermic fish that are found in the Niger Delta Rivers (Ogbone and Ajayi, 2015). During the dry season, when the water levels drop, African lungfish can burrow into the mud and estivate (aestivation is a state of dormancy that is similar to hibernation). This allows them to survive until the water levels rise again. Amphibians are ectothermic animals that can live both in water and on land. In the Niger Delta rivers, there are a variety of amphibians, including frogs, toads, and salamanders (Ogbone and Ajayi, 2015). During the hot season, amphibians tend to be more active at night and during the cooler parts of the day. They may also spend more time in the water to stay cool. These are just a few examples of how temperature can affect the behaviour of ectothermic animals in the Niger Delta Rivers, Nigeria. The behavioural effects of temperature on these animals are complex and varied and more research is needed to fully understand them (Ogbone *et al.,* 2015, Abowei (2011).

Several physiological thermoregulations abound as response to aquatic temperature (Ogbone *et al.,* 2015 and Adolph (2015)). Temperature has a significant impact on the movement of aquatic species in the Niger Delta area.

Aquatic species are ectothermic, meaning that they rely on their external environment to regulate their body temperature. As a result, they are very sensitive to changes in temperature. A rise in temperature can cause aquatic species to become more active. However, if the temperature rises too high, it can lead to stress, reduced metabolism, and even death. This is because aquatic species need a certain amount of energy to regulate their body temperature. If the temperature rises too high, they may not have enough energy to do this, and may die (Braide *et al.*, 2013).

Temperature can also affect the movement of aquatic species in other ways (Araoye, 2008). For example, some fish migrate to cooler waters during the summer months. Others may hide in shaded areas or burrow into the mud to avoid the heat. Here are some specific examples of how temperature influences the movement of aquatic species in the Niger Delta area (Ibemere and Anyanwu, 2015).

Fish are particularly sensitive to changes in temperature. A rise in temperature can cause fish to become more active, but it can also lead to stress, reduced metabolism, and even death. Some fish species in the Niger Delta region, such as the Nile tilapia, are more tolerant of high temperatures than others. However, even these species can be affected by extreme heat (Ibim *et al.*, 2020). Mangrove crabs are important part of the ecosystem in the Niger Delta region, they play a role in nutrient cycling and decomposition. Mangrove crabs are also a food source for many other animals, including fish, birds and mammals.

Mangrove crabs are relatively tolerant of high temperatures, but they can be affected by extreme heat (Ovuru and Dambo, 2002, Alagon and Gijo, 2022). Sea turtles are a threatened species that can be found in the coastal waters of the Niger Delta region. Sea turtles are ectothermic animals, and they are particularly sensitive to changes in temperature. A rise in temperature can cause sea turtles to become more stressed and less active. It can also lead to changes in their nesting behaviour. These are just a few examples of how temperature influences the movement of aquatic species in the Niger Delta area.

Temperature and dissolved oxygen have been noted to affect some behavioural pattern in the aqua-biota and thus influencing the correlation of the predator and the prey (Dallas, ~~2008~~2007). It has been observed to influence the feeding activities of the aqua-biota (Braide *et al.*, 2013). Trophic interactions may be influenced by aquatic temperature, as temperature increases, the metabolic rate of species also increase, this will likely increased competition for food and resources and changes in predator-prey dynamics. Studies on the zooplankton and phytoplankton interactions, observed that as temperature increases, the growth of phytoplankton increases, which may lead to bloom of phytoplankton and a crash in zooplankton population. This crash causes a cascading effect on the food web. Temperature may influence aqua-biota movement, especially fish and other fauna (Dallas, ~~2008~~2007). The aqua-biota employ thermal refugia (this include, undercut banks and hanging vegetation cover (Bell, 2006); vertical stratification in pools (Elliot, 2000, Talle *et al.*, 2006), cold water patches, floodplain tail seeps and stratified pools (Ebersole *et al.*, 2001) and usually regulate their temperature by migrating to regions of cooler water when surrounding water temperatures are not favourable (Elliot, 2000; Gardner *et al.*, 2000; Ogbone *et al.*, 2015) have studied extensively on the influence on temperature on movement of aquatic species in the Niger Delta Area.

Reproduction and Life Histories of Aqua-Biota responses to Temperature

There is a correlation between reproduction processes in aqua-biota, with some environmental physical characteristics, especially temperature, (Dallas, 2008 and Akpan *et al.*, 2022). Studies has also confirmed that the stages of reproduction are the most impactful with thermal disruption (Ebenezer *et al.*, 2014). Fish developmental process and spawning could be initiated by temperature and other factors (Dallas, 2008, Ogbone and Ajayi, 2015; Ayotunde and Ogbenebube, 2016). Fish usually spawn during the warm periods of the season, probably due to the fact that the egg embryo rates and development of larval stage are correlated to a positive level with temperature and also due to food abundance (Ayotunde and Ogbenebube, 2016;), Braide *et al.*, (2013). Studies conducted by Ogbone and Ajayi (2015) found that the Nile Tilapia spawns throughout the year in Akwa Ibom Rivers and that spawning is triggered by the onset of the rainy season, when water levels rise and temperature increases. Other studies regarding spawning in the waters of Niger Delta region have been carried out by Ayotunde and Ogbenebube (2016), Abowei (2011) and Ebenezer *et al.*, (2014). Aquatic temperature is noted to be the most vital environmental characteristics affecting the growth of aqua-biota (Marine and Cech, 2004;~~,~~ Braide *et al.*, 2013) with growth development taking place within a certain thermal regime.

Functional and Structural Responses of Aqua-Biota to Temperature

The growth of aqua-biota, including its survivability and metabolic activities are greatly influenced by temperature (Ruma *et al.*, 2017), as the determines the functioning of the ecological system through its regulation as exemplified by the process of photosynthesis (Klshi *et al.*, 2005;~~,~~ Dallas, 2008). Researches have reported that photosynthesis, which is the main stay of primary production escalates with temperature. This escalation may re-structure the ecological system and by extension, impact on their functions (Dallas, ~~2008~~2007).

Aquatic temperature greatly influences the geographical distribution of some species (Ibemere and Anyanwu, 2014; Nwogu and Oguzie, 2016); Nwaichi and Ekenedo (2017) and the changes in the aquatic temperature may cause changes in the community structure of such species. In Niger Delta region, aquatic temperature changes have been significantly positively correlated with the diversity of species and the maximum temperature attained at dry season could limit the emergence of some kind of species (Nwogu and Oguzie, 2016).

Assessing the Impacts of Temperature Variation on Aqua-Biota

The impact of aquatic temperature variation on aqua-biota are assessed, studied and monitored by insitu and ex-situ observations (Dallas, ~~2008~~2007;~~,~~ Akpan *et al.*, 2013). Both methods can be used in pari-pasu, with its attendant advantages and disadvantages (Beitinger, *et al.*, 2000).

Several studies in Niger Delta Region have used variety of methods to assessed the impacts of temperature variations on aqua-biota, this includes field surveys, laboratory experiments and modelling (Braide *et al.*, 2013 and Ebenezer *et al.*, 2014). The field surveys and laboratory experiment by Braide *et al.*, (2013) revealed that the abundance and diversity of fish species in the Niger Delta region had decreased with time and that this was correlated with an elevation in aquatic temperature, while the laboratory experiment opined that juvenile fish species were more sensitive to temperature variation than adult fish and that exposure to increase temperatures led to decreased growth, reproduction and survival.

Another study by Ibemere and Anyanwu (2015), using the field surveys method to investigate the correlation between aquatic temperature and fish species distribution in a Niger Delta river ecological system, the outcome exposed that the thermal niche of most species of fish in the Niger Delta river ecosystem was relatively narrow, depicting that they could cope with a small range of aquatic temperatures. Temperature sensitive species were found to be more abundant in cooler waters, while temperature-tolerant species were found to be more abundant in warmer waters.

Ex-situ studies on the thermal tolerance of aqua-biota are much, these impacts may be studied with respect to aqua-biota's lethal limits, and behavioural avoidance strategies. For a deeper extent knowledge of the input of aquatic temperature on aqua-biota, a combination of the insitu and ex-situ method is more reliable (Dulloo *et al.*, 2010).

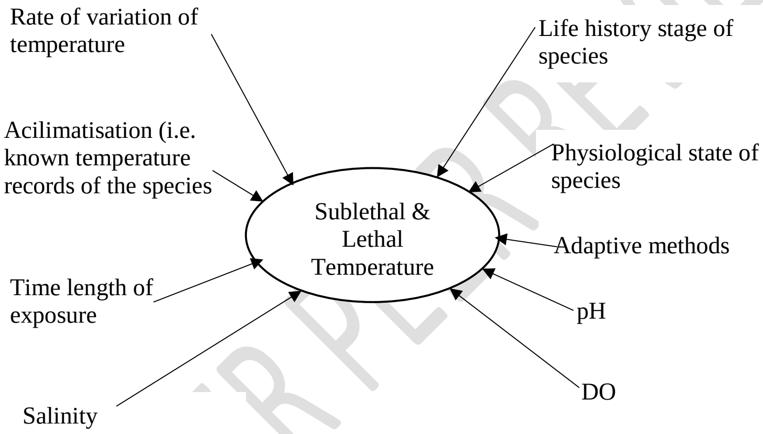


Fig. III: Factors Influencing the Sublethal and Lethal temperature for aqua-biota (adapted from Laugford, 1990, Nwaichi and Ekenedo, 2017)

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Sublethal and Lethal Impacts on Aqua-Biota

The sublethal and lethal impacts are influenced by various factors (F~~f~~ig. III~~iii~~). These are exposed through laboratory studies, which is exemplified by ex-situ study with its laid down procedure (Dallas, 2008), Beitinger *et al.*, 2000, several studies in Niger Delta have documented on these impacts on aqua-biota (Nwaichi and Ekenedo, 2017, Nwogu and Oguzie (2016); Braide *et al.*, (2013).

The lethal temperature for most species were in the range of 32-34 degree Celsius (Ebenezer *et al.,* 2014). Studies have shown the lethal impact of temperature on aqua-biota (Braide *et al.,* 2013; Ebenezer *et al.,* 2014 and Nwogu and Oguzie, 2016). Sublethal impacts are mainly on fecundity and it processes, the period of exposure is vital in studying sublethal impacts (Dallas, ~~2008~~2007). Various studies have examined on sublethal effects on aqua-biota in Niger Delta region of Nigeria, (Ibemere and Anyanwu, 2015; Ebenezer *et al.,* 2014; Nwailie and Elenedo, 2017). They concluded that the impacts include; reduced growth development, decreased reproduction and fecundity, increased susceptibility to diseases and parasites. Changes in feeding behaviour and changes in habitat use and migration patterns. Generally, the subject (sublethal and lethal) impact significantly on the aqua-biota species in the region and pose-major threat to the ecological system and this seriously influenced other environmental factors viz: salinity, ph and dissolved oxygen, (Ebenezer *et al.*,2014).

Mechanism of Response to Temperature Changes

Aqua-biota in the Niger Delta area of Nigeria exhibit a variety of mechanism of response to temperature changes in its ecological system. This include; behavioural preferences and avoidance mechanisms (Nwaichi and Ekenedo, 2017). On behavioural preferences; this include, microhabitat selection, basking behaviour and thermoregulatory behaviour. On avoidance mechanisms; this include behavioural avoidance and physiological avoidance. These have been extensively studied by various scientists (Braide *et al.,* 2013; Ebenezer *et al.,* 2014; Ibemere and Anyanw, 2015; Nwogu and Oguzie, 2016; ~~and~~ Nwaichi, and Ekenedo, 2017). Generally, the concluded that aqua-biota in the region have a wide range of mechanism, which include behavioural preferences and avoidance mechanism in response to temperature changes. These assist the aqua-biota to survive and reproduce in a variety of temperature changes.

Aquatic Temperature Criteria for the Protection of Aquatic Ecological Systems

A study of the criteria for aquatic temperature in ecological systems beams on the need of being knowledgeable in tempo-spatial variability in aquatic temperature. Extracting the correct temperature criteria to adopt as a guide in protecting aqua-biota is complicated due to variable nature of temperature in aquatic systems, plus the variable temperature needs of the aqua-biota. Temperature guide consist of threshold temperature; this indicate when adverse or reverse biological response may likely occur and an averaging time that indexes the period of exposure readily to ignite the response (Sulivan *et al.*, 2000). The combination of the temperature guide is an indication of the negativity imposed by environmental temperature to the targeted aqua-biota. Overview of the current temperature criteria developed in Nigeria which Niger Delta area belongs and since other part of Africa have been discussed by Ighalo and Adeniyi (2020) and Ewezie *et al.*, (2021).

Conclusion

This review study beams on the complexity of temperature in the aquatic ecological system, the need of being knowledgeable in tempo-spatial variability in aquatic temperature; and the various responses of aqua-biota to temperature (thermal) stress, and the anthropogenic agenda that modified the aquatic temperature and the present global challenge of the aquatic ecological system-the climate change.

Niger Delta region is an area in Nigeria already stressed by the menace of aquatic pollution, masterminded by anthropogenic agenda due to quest of industrialization. These problems are intensified ~~pregnated~~ by risk-bound conditions effected by greater demand for ~~need of~~ water and its resources, exposes the need for being knowledgeable on the thermal facts in aquatic ~~ecological systems in~~ecosystems of the Niger Delta plus the triggering parameters of such aqua-biota is of great essence.

The review has pointed out that there is dearth of information in temperature related data in Niger Delta Region. Baseline data on aquatic temperature and thermal needs of aqua-biota is very vital to the appropriate management of the aquatic ecological systems. It is necessary that this knowledge gap be worked on through a composite study on the aquatic ecological systems and its temperature details, through an experimental design of in-situ and ex-situ studies targeting on biotic responses to thermal triggers, and subjecting it to exact aquatic temperature model.

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