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The occurrence of the brine shrimp, *Artemia franciscana* (Kellog 1906) in Kenya and the potential economic impacts among Kenyan coastal communities

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ABSTRACT
The occurrence of *Artemia* populations in Kenyan coast is a noble happening. However, much information is lacking concerning its exploitation for Larviculture. This paper reviews inoculation of *Artemia* in the Kenyan coast and the potential benefits it holds for the local communities. The eight salt works along the Kenyan coast are credited for *Artemia* production since *Artemia franciscana* was first inoculated in Kenya 2 decades ago. The Kenyan *Artemia* is genetically similar to those from San Francisco Bay and Great Salt Lake, which are so far considered standard in aquaculture nutrition. The Kenyan *Artemia* strain has adapted to the local environmental conditions and is reproductively superior to the original inoculants. Optimization and application of *Artemia* in local Larviculture initiatives stands between aquaculture successes in Kenya. Indeed, *Artemia* is the neglected asset that can improve people's economy. Further studies are required to educate the locals on the potential economic gains from *Artemia*.

Keywords: Kenya, *Artemia franciscana*, Economics, Local communities

1. Introduction

1.1 General features of the genus *Artemia*

The genus *Artemia* (Leach, 1819) (Branchiopoda, Anostraca) is a cosmopolitan taxon typically adapted to live in stressful environmental conditions of hypersaline habitats such as salt lakes, coastal lagoons and solar salt works found almost all over the world [1, 2]. Being osmotolerant, *Artemia* can withstand habitats whose salinity levels range between 10 - 340 g L^{-1} with fluctuating ionic composition and temperature profiles [3]. *Artemia franciscana* is native to the American continent and commercially available cysts mainly originate from Great Salt Lake, Utah and San Francisco Bay, California [4]. Cysts from the latter have been used in many (deliberate or not) inoculations around the world [5]. To date, there is no artificial feed that can completely substitute for *Artemia*, thus *Artemia* nauplii remains most essential in many hatchery operations [6]. Although other types of animal live food exist for these purposes, for example Moina and Daphnia (Cladocera) and Brachionus (Rotifera), *Artemia* is still the best nursery food for fishes and crustaceans thanks to the high protein and fatty acid contents [6]. *Artemia* is rich in HUFA (DHA and EPA), which are considered essential fatty acids for larval fish development [7]. In fact, freshly hatched nauplii have a higher nutritional value than 2 or 3 day old nauplii [8]. Compared to inert feed, live animal food can be administered in larger amounts thus covering a longer non-feeding period, without compromising water quality. *Artemia* cysts can be stored for many years, appropriately packed and transported all over the world and the cysts can be easily hatched in seawater to produce nauplii [8]. Thus, no separate culturing tanks are needed to obtain large quantities of live food. Through bioencapsulation, *Artemia* can be enriched with additional nutrients to improve its nutritional quality and the production of the cultured species [9].

The brine shrimp *Artemia* is a primitive arthropod with a thin chitin coated segmented body growing to an adult size of about 8 - 12 mm long [10]. Whereas the adult males have a retractile penis, females have a conical brood sac for storing eggs or nauplii during reproduction cycles [11]. The physiological adaptation of *Artemia* includes efficient respiratory pigments to counter low oxygen tensions in hypersaline [12]. The most extensively discussed ecological aspect of the genus *Artemia* is the evolution of two distinctly different paths of development, which includes the production of diapausing cysts during harsh environmental conditions and the directly developing embryos during favourable conditions (Fig. 1) [13]. *Artemia* non-selectively filter feeds on phytoplankton and bacteria [14]. The high media salinities eliminate *Artemia* competitors leading to thick *Artemia* monoculture densities [15]. Dispersion of *Artemia* cysts is mainly accomplished by man, wind and waterfowl, especially flamingos [16].

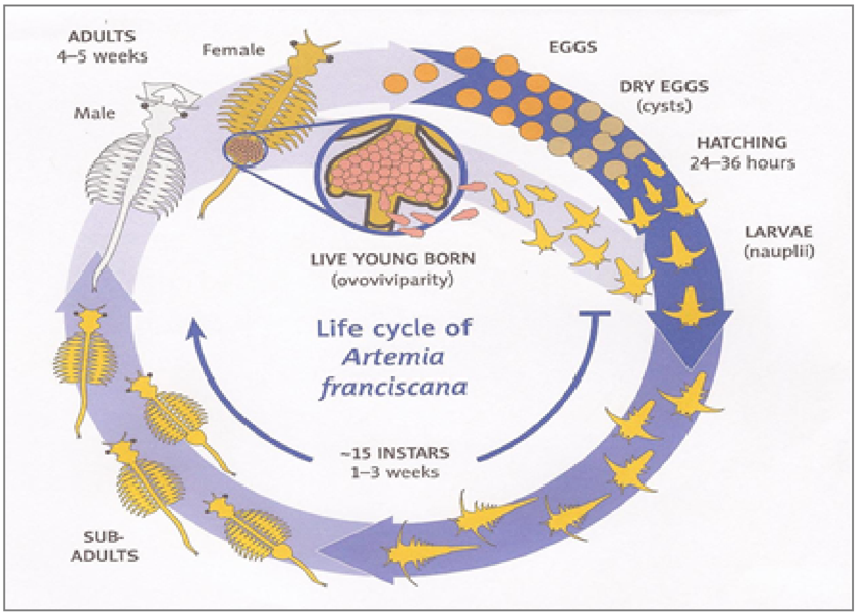

Fig 1: Life cycle of *Artemia franciscana*

1.2 Economic and ecological importance of *Artemia*

The use of *Artemia* nauplii as live fish food began in the 1930s when scientists discovered their unmatched nutritional values [17]. Indeed, many authors agree that *Artemia* could be the solution to mass mortalities experienced in many global fish and shellfish hatcheries [17, 18, 19]. *Artemia* nauplii can be used as a vehicle of spawning hormone to cure fish diseases and stimulate spawning in brood stocks of shrimps [20]. The *Artemia* nauplii are carriers of probiotics in marine fish [21].

Today, over 2,000 tons of *Artemia* dry cysts, costing about 65 USD kg $^{-1}$ are used annually to feed fish and shellfish [22]. Salt production companies now agree that salt work operations require substantial populations of *Artemia* to control the problems associated with algal blooms and to improve salt quality. Scientists consider *Artemia* as a model organism for research fields such environmental ecotoxicology [23], evolutionary and genetic studies [24].

2. Geographical distribution of *Artemia* species

2.1 Global distribution

The fact that brine shrimp *Artemia* can inhabit a wide range of hypersaline environments gives them a wide global geographical representation. So far, discrete *Artemia* populations have been identified in about 600 natural salt lakes and salt works along the coastlines of tropical, subtropical and temperate regions and further survey efforts are still on course to identify more *Artemia* biotopes [24]. Whereas *A. franciscana* is native in North, Central and South America [25], other *Artemia* species include: *Artemia persimilis* of South America [26], *Artemia salina* in the Mediterranean basin [26], *Artemia urmiana* of Lake Urmia, Iran [27, 28], *Artemia sinica* in China [29], *Artemia tibetiana* from Tibet [30] and *Artemia sp.* in Kazakhstan [31]. *Artemia* has been inoculated in Brazil, Australia [32], Philippines, Thailand [33], India and Sri Lanka [34] and Vietnam [35].

2.2 *Artemia* in Africa

Most African countries have potential *Artemia* habitats thanks to the favourable climatic conditions. Although information about the *Artemia* presence in African is still scanty, *A. salina, A. franciscana* and parthenogenetic *Artemia* populations have been identified in Tunisia [36]. The existence of a bisexual population of *Artemia* and *A. salina* in Morocco, Libya and Egypt has been scientifically authenticated [37]. Most recently, the studies revealed that *Artemia* cysts in the coastal Tanga in Tanzania are genetically similar to the Kenyan *Artemia franciscana* populations [37]. Speculations are also high that *Artemia* cysts exist on the shore of a salt lake in West Uganda but there is no literature to support this claim.

2.3 The Presence of *Artemia franciscana* in the Kenyan coast

Between 1984 and 1986, a non-native *A. franciscana* was first introduced along the Kenyan coast courtesy of a collaborative project between Kenya Marine & Fisheries Research Institute (KMFRI) and the Belgian Agency for Development Cooperation (BADC). The specific aim was to assess the potential of *Artemia* production in Kenyan coastal salt works. Indeed, studies confirmed the existence of *A. franciscan*a in Kensalt, Malindi and Kurawa salt works in the Kenyan coast almost 2 decades after original inoculation [38]. Today, the *A. franciscana* has spread (perhaps through wind, birds and human activities) and has permanently colonised the Kenyan coast, where eight salt work companies exist with each having different *Artemia* inoculation policies. Studies revealed that the current *Artemia* in Kenya are genetically similar to the original inoculants from San Francisco Bay (SFB), USA [39]. Despite genetic similarity, the non-native *A. franciscana* has successfully adapted to the Kenyan environmental conditions and are reproductively superior to the original inoculants [40]. This paper aims to document the occurrence of *Artemia* in the

Kenyan coast almost 3 decades after first inoculation. The potential economic gains of *Artemia* to the Kenyan coastal communities have also been addressed.

2.4 *Artemia* production in Kenya

Artemia is mainly produced in the commercial and artisanal salt pans owned by salt producing companies in the Malindi area along the Kenyan coast (Fig. 2). In Kenya, controlled *Artemia* production is done in coastal salt works in which sea water salinity is increased by evaporation. *Artemia* is cultivated in permanent and seasonal units. The latter refers to the artisanal salt works and only operates during the dry season when the evaporation outweighs the precipitation. The ponds are small sized (about 100 m^2) with depths ranging from 0.1 m to 0.6 m. and are largely managed individually. The permanent salt works are much more complex systems with a number of joined evaporation ponds and crystallizers; the size of the ponds is between few to several hundreds of hectares having a depth of 0.5 m to 1.5 m. Sea water is pumped into the first pond and flows to the other evaporation ponds by gravity. In doing so, the salinity is raised due to increasing evaporation of water. *Artemia* occurs in ponds at medium salinity levels, i.e. minimum 80 g/L and maximum 140 g/L; cyst production happens in the ponds with salinity between 80 to 250 g/L [41].

In 2009 the management of Fundisha salt works Company started an integrated salt-*Artemia* production in their farm after learning about the importance of *Artemia* in the salt production process. They imported *Artemia* cysts from Great Salt Lake (GSL) to inoculate the ponds. Currently, the farm practice regular pond inoculations every production season using nauplii hatched from locally harvested cysts and commercial GSL *Artemia* cysts (M. Mukami – Kenya MFRI pers. communication). In Kurawa salt works, SFB *Artemia* cysts were re-inoculated into the salt ponds to boost *Artemia* population in 2009 and 2010. Since then, the management does routine inoculation of *Artemia* in the months of June, July and August using nauplii hatched from harvested *Artemia* cysts.

Between 1992 and 1993, Kensalt Company experienced a devastating algal bloom that threatened to shut down the farm forcing the management to use *Artemia* to biologically control the algal blooms. The *Artemia* population used for inoculation at Kensalt ponds was harvested from Kurawa salt works. Today, Kensalt Company performs a routine re-inoculation program using nauplii hatched from harvested cysts every September. In Kemu salt farm, *Artemia* was first introduced in 2008 using the GSL strain. An organised re-inoculation program exists where commercial GSL *Artemia* cysts are regularly hatched and the naupli are grown for 3 weeks before inoculation in ponds whose salinity is between 150 - 200 gL^{-1} (Verbal communication M. Mukami, KMFRI).

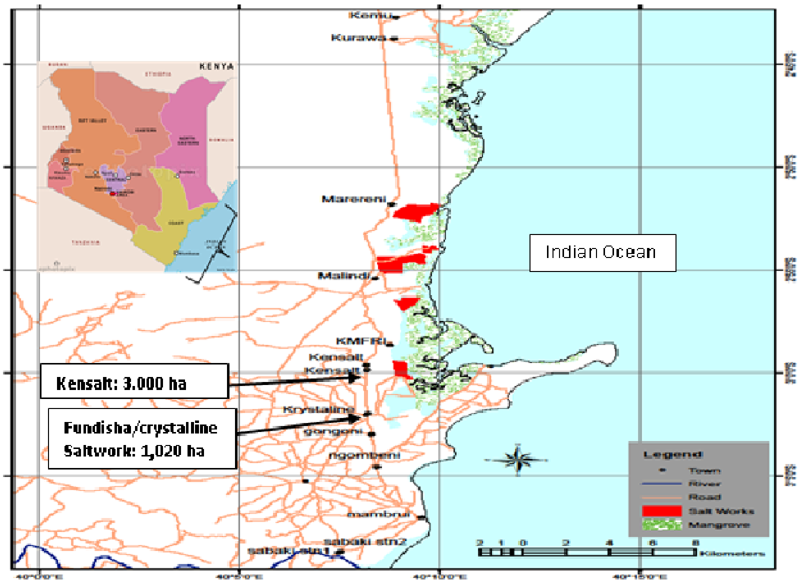

Fig 1: Map of the Kenyan coast showing the location of the salt belt and a more detailed impression of the salt belt showing the individual salt producing companies in a North – South Orientation. Fundisha salt work is also called Crystalline.

The *Artemia* population present in Marine salt works is believed to have spread from the initial inoculations that where done in Fundisha and Kurawa salt works in the 1980s and from the neighbouring Kensalt farm in 1990s. Despite the fact that there is no organized biological management of the salt works using *Artemia* in this farm, *Artemia* are seen year round, confirming the permanent *Artemia* populations.

There has never been any intentional effort to inoculate *Artemia* in the salt pans of the Malindi salt works Company. It is speculated that the *Artemia* currently present in Malindi ponds must be original SFB *Artemia* inoculations made in Kurawa and Fundisha salt works between 1984 and 1986. Anyway, *Artemia* cyst or biomass production is not the main priority in any of the salt farms in Kenya. Therefore records on cyst production are scanty with some companies such as Kurawa, Fundisha and Kensalt reporting harvests less than 10 kg of cysts per season and are used for re-inoculation purposes. Studies about the reproductive characteristics of Kenyan *A. franciscana* revealed that the original *Artemia* from SFB inoculated on the Kenyan coast almost two decades ago has successfully adapted to the local environmental conditions [42]. They found that Kenyan *A. franciscana* had a higher number of broods per female (Table 1) and better survival at 33 ºC compared to the original SFB *Artemia* strain (Fig. 3).

Table 1: Reproductive and lifespan characteristics for experimental *Artemia* strains at 33 °C Kn1 and Kn2: *Artemia franciscana* from Kenyan coast, VC: Vihn Chau Artemia strain from Vietnam, SFB: Artemia franciscana from San Francisco Bay, USA. Values with similar superscript are not significantly different

Reproductive Characteristics	Culture temperature at 33 °C			
	Kn1	Kn2	VC	SFB
Female pre-reproductive period (days)	16.3^{b}	15.9^{ab}	15.2^{a}	15.9^{ab}
Female reproductive period (days)	4.6^{ab}	5.9^{b}	4.8^{ab}	2.3^{a}
Total broods per female	1.7^{ab}	2.3^{b}	1.8^{ab}	1.3^{a}
Oviparous broods per female	1.0^{a}	1.3^{a}	1.2^{a}	0.0^{a}
Ovoviviparous broods per female	2.0^{a}	2.0^{a}	1.5^{a}	1.3^{a}
Total offspring per female	39.0^{ab}	67.8^{b}	52.0^{b}	14.0^{a}
Offspring per female per day	6.8^{b}	6.3^{b}	6.6^{b}	1.9^{a}
Percent offspring encysted	75.0^{b}	52.1^{b}	18.3^{ab}	0.0^{a}
Brood interval (days)	1.8^{ab}	2.4^{b}	1.4^{a}	1.1^{a}

(Courtesy of [42]

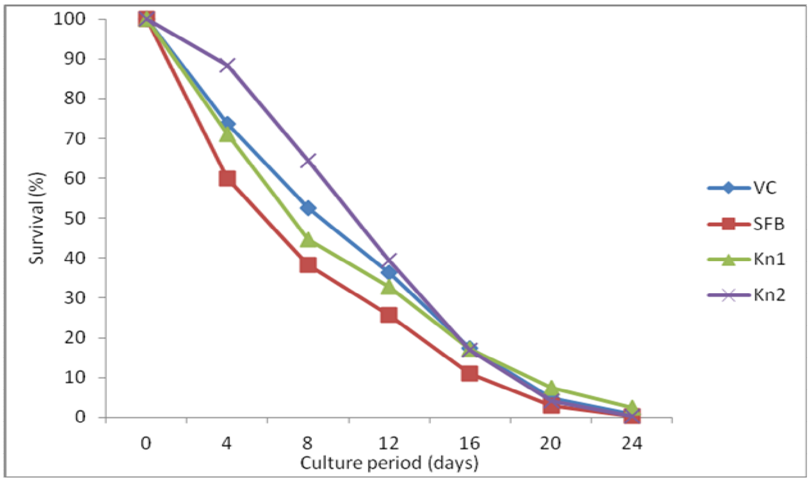

Fig 3: Mean survival of the experimental *Artemia* strains at 33 °C for the entire culture period. VC: Vihn Chau strain from Vietnam, SFB: Artemia franciscana from San Francisco Bay, USA, Kn1 and Kn2: Kenyan Artemia franciscana strains. Courtesy of [42]

3. Potential economic benefits of *Artemia* in Kenya

There is no doubt that the Kenyan coast has a high aquaculture potential. Indeed, the presence of the nutritious small, soft-bodied crustacean (*Artemia*) in the Kenyan coast can only be described as a 'gold mine', whose potentials should be unlocked to the local people. For a long time marine fish farming in Kenya has lagged behind due to lack of proper food for larviculture. The occurrence of *Artemia* at the coastal Kenya is a great opportunity, providing a chance to increase food production and create employment through enhancing emerging mariculture initiatives, such as mullet, milkfish, crabs and prawns, which seem to perform better in ponds than in natural waters [43]. Commercial culture of shrimps mussels, oysters, and abalone are yet to be perfected in Kenya [44]. Efficient exploitation of the local *Artemia* in the coast region can create thousands of employment opportunities, reduce food insecurity and reduce malnutrition among the communities. The pros of integrating the production of salt and *Artemia* are enormous. More profits can be derived from improved salt quality, production of *Artemia* biomass and cysts at the same time using same labour, land and management. The Kenyan coastal local community development centres, which have already developed to some extent, could become targets of demonstration of *Artemia* farming activities to improve the lives of rural communities. Stiff competition and scarcity for freshwater in Kenya limits freshwater aquaculture and has contributed to food insecurity [44]. Marine water is abundant and therefore provides an opportunity to eradicate food insecurity only if marine fish culture practices are enhanced. Indeed *Artemia* presence could be harnessed to boost marine fish farming. The global estimate of the annual *Artemia* cyst market to feed fish and shellfish is over 2,000 tons, costing about 65 USD Kg $^{-1}$. Kenya can emulate the success of Vietnam, which has become one of the leading traders in *Artemia* cysts in the world market [45]. Kenya has the opportunity to exploit this opportunity and join other world leaders in the global *Artemia* cyst trade.

The Kenyan salt manufacturing companies have leant that substantial population of *Artemia* in the salt ponds lead to production of high valued salt. *Artemia* filters out excess phytoplankton, which leads to smaller and lower quality salt crystals [46]. Today, several individuals, groups, and salt companies in the Kenyan coast are gearing themselves to engage in the production of the *Artemia* cysts and/or biomass as a business venture to improve their businesses and livelihoods [47].

In Kenya, 1 hectare of *Artemia* ponds can be well managed by a single worker. It would require about 40 to100 *Artemia* nauplii per litre to inoculate 1 pond. With good *Artemia* cysts, 1 gram can hatch between 200,000 to 300,000 naplii (Lavens and Sorgeloos 1996). A pond of 1 ha whose water level is maintained at 30 cm can be inoculated with 3.0×10^8 *Artemia* nauplii. This means that a single ha of pond requires about 1.1Kg of dry *Artemia* cysts to adequately stock. In a single season of 6 months, 1 ha of *Artemia* pond can produce about 33 kg dry weight of cysts. This translates to gross profit of USD 2,145 assuming the current market rate of USD 65 kg $^{-1}$. Assuming operational costs of 30%, a net profit of USD 1,500 can be realised in 1 ha pond within 6 months. Besides cyst production one hectare can produce 250 Kgs of *Artemia* biomass. Assuming a price of USD 1.7 kg^{-1} of *Artemia* biomass, a farmer can obtain additional net profit of USD 425. Together, approximately net profit of USD 320 ha $^{-1}$ month $^{-1}$ can be realised. This is just enough for an average Kenyan farmer to maintain a rather decent living in a rural set up.

The *Artemia* pond culture in Kenyan coast involves both men and women. Despite fishing being the main economic activity in the region, dwindling capture fish stocks and low income generated has forced many people to seek other alternatives [48], *Artemia* culture may be the solution for this problem to boost aquaculture sector and hence food security. The ongoing *Artemia* production project involving Gent University and KMFRI at the Kenyan coast has significantly raised people's awareness about the economics gains of Artemia. It is important that these people should be trained in modern methods of Artemia culture to further improve their livelihoods.

4. Conclusion and recommendations

The *Artemia* population is permanently present in the Kenyan coast. The decision to optimise the production of *Artemia* by the local communities and use *Artemia* in marine fish larviculture initiatives stands between aquaculture successes in Kenyan coast. Indeed, this is forgotten assets that can turnaround the aquaculture production at the Kenyan coast and immensely improves people's standards of living. It should be applied on the species of fish larvae being produced as the best way to deliver nutrients to provide the feeding requirements of the fish species. The brine shrimps have been successfully used to culture many species of marine fish through the larval phase. Well documented culture protocols, improvements in nutritional enrichments, and readily available cysts make the *Artemia* live food appealing. Determining economic costs and benefits of live food organisms (*Artemia*) should include any improvements in survival, growth rate, and stress resistance gained by the fish being cultured to fully account for the benefits. More economic and reproductive studies should be done on the Kenyan *Artemia* to unlock the potential and educate the local communities to invest in *Artemia* culture.

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