

**FISH RECRUITMENT DYNAMICS IN SEAGRASS HABITATS OF VARYING
COVERAGE IN WATAMU, NORTHERN COASTAL KENYA**

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Master of Environmental Science of Pwani University**

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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award

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DEDICATION

To the lives we carried but never held in our arms, you are dearly missed.

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ABSTRACT

Seagrass habitats are important nursery and recruitment areas for marine fishes; hence their conservation is an important aspect in fishery management. This study examined patterns in fish recruitment in seagrass habitats of varying seagrass cover; specifically, larvae and juvenile composition and abundance in seagrass habitats of Watamu. The study tested the hypotheses that sites, seasonality and hydrographic parameters influence larvae and juvenile composition and abundance. Two sites of varying seagrass cover were identified, Watamu Blue Lagoon (Site 1) and Watamu Beach (Site 2). Monthly samples of fish larvae and juveniles were collected during the Southeast monsoon (June-August) and Northeast monsoon (November-January) from 2019 to 2021. Environmental variables (water temperature, salinity and chlorophyll-*a*) were measured at each sampling occasion. Fish larvae were sampled by towing a 500 μm net behind a boat at a speed of 1 knot (meter per second) for 20 minutes, while juvenile fish were collected using a seine net of stretch mesh size 1.5 cm. Larvae were sorted on a dissecting microscope, identified to the lowest taxa possible. Developmental stage of larvae was determined as either preflexion, flexion or postflexion. Larvae belonged to a total of 35 families while juvenile belonged to 28 families. Majority of larvae (60%) were collected during the Northeast Monsoon (NEM). Larvae at preflexion stage dominated the catch during the NEM season while Southeast Monsoon (SEM) samples were dominated by larvae at postflexion stage. For juveniles, the dominant species were *Lutjanus fulviflamma* (family Lutjanidae), *Lethrinus harak* and *L. mahsena* (family Lethrinidae) and *Siganus sutor* (family Siganidae). Mean larval abundance was highest in November 2019 with a peak of 8.09 in site 1 and 12.14 larvae/100m³ in site 2. Mean juvenile abundance was also highest in year 1, December with 22 fish for site 1 and 50 fish in site 2. Differences in larval and juvenile abundance between the two sites were not significant (larvae $p = 0.94$, juvenile $p=0.32$), seasonal variation in larval abundance was significant for larval abundance (larvae $p = 0.04$, juvenile = 0.85). A few fish families such as Lutjanidae and Siganidae, were sampled both as larvae and as juveniles. A seasonal pattern was observed

in larval and juvenile abundance, with an abundant and diverse larval and juvenile assemblage sampled in NEM compared to SEM. A generalized linear model showed that Chlorophyll-*a*, temperature, and zooplankton abundance positively correlated with larval abundance. Chlorophyll-*a* (positively) and salinity (negatively) correlated with juvenile abundance. The findings of the study demonstrate the importance of seagrass habitat to larval and juvenile developmental stages of marine fishes.

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CHAPTER ONE: INTRODUCTION

1.1: Background information

The annual economic contribution of seagrass and their services to humanity has been valued at about US \$19,000 per hectare globally (Wawo *et al.*, 2014). Ecologically, they contribute to surface carbon sequestration and stabilization of the sea floor by regulating sedimentation (Boström *et al.*, 2011; Dewsbury *et al.*, 2016). They also offer shoreline protection, nutrient cycling and habitation of epifauna (Orth *et al.*, 2020). As habitats, they provide grazing ground for a number of vertebrates and invertebrates, in fact, according to Schaffler *et al.*, (2013) and Igulu *et al.*, (2014). They are major fish nursery habitat.

Nurseries are habitats that enable growth and survival of juveniles (Cheminée *et al.*, 2021). They contribute greatly to recruitment by allowing growth of juveniles before they move to other habitats as sub-adults (Beck *et al.*, 2001; Parsons *et al.*, 2014). Functional nursery habitats have high densities of juvenile fishes, mostly juveniles whose adults are found offshore or in adjacent reefs (Kimirei, 2012; Parsons *et al.*, 2014; Sievers *et al.* 2020). A nursery offers an abundant supply of nutrients, supporting rapid growth of larvae and juvenile (Gross *et al.*, 2019). The high habitat complexity of a nursery enhance survival of juveniles from predation by limiting movement and vision of larger predators (Alonso *et al.*, 2017; Gross *et al.*, 2019). The described attributes define the characteristics of seagrass beds. Seagrass beds are efficient nurseries because of the complex intertwining of seagrass shoots that provide protection of larvae and juveniles from predation (Orth *et al.*, 1984; McCloskey and Unsworth, 2015).

Besides the qualities that have been described above, nurseries allows for connectivity between habitats enabling colonization by juveniles or larvae, migration of subadults to adult habitats, and adequate interaction within the community (Berkström *et al.*, 2013; Irisson *et al.*, 2015; Whitfield and Patrick 2015). The nearness of seagrass beds to other critical habitats like coral reefs facilitates trophic transfers and cross-habitat utilization by many fish species (Berkström *et al.*, 2013).

Despite their major contribution to humanity and to biodiversity in general, seagrass have been facing disturbance, from both natural and anthropogenic factors, causing patchiness of seagrass beds (Sweatman *et al.*, 2017). Patchy seagrass beds are scattered units of seagrass beds and have 15% or more of bare sediment between and among the patches. A continuous bed has less than 15% bare sediment within seagrass delineated areas. (Handley 1994). Natural factors that cause patchiness of seagrass habitats are herbivory from sea urchin, wave motion, climate change, storms and hurricanes, whereas, human induced factors that affect seagrass cover are shoreline construction, dredging and eutrophication (MacUra *et al.*, 2016). In Zanzibar, for instance, the main cause for the decline seagrass distribution is human induced: excess gleaning, engine scars, strong winds, and literal digging (Nordlund *et al.*, 2010).

Patchy seagrass cannot perform their ecosystem functions effectively, and are therefore likely to have lower diversity and distribution of fish species (Yeager *et al.*, 2019). The early fish stages prefer complex habitats of shallow macrophyte, sheltered bays and inlets (Yeager *et al.*, 2019). The patched landscapes may have considerably different microclimates, alter predator–prey dynamics, the physical and ecological processes, thus contribute to changes in marine communities within a patch (Fahrig, 2003; Yeager *et al.*, 2016). Therefore, investigating the quality of these complex structures and their interaction with fish communities is important in enhancing our understanding of species environment relationships, thus monitor the sustainability of fishery production (Rodríguez *et al.*, 2017; Staveley *et al.*, 2020). Continuous seagrass covered areas are hence assumed to be healthy because they attract a greater assemblage of ichthyofauna and fish juveniles (Gross *et al.*, 2017; Parsons *et al.*, 2014).

This study compared fish larvae and juvenile assemblages between patchy and continuous seagrass beds of Watamu Bay, and the recruitment capability of these sites by comparing abundances between the two sites. This study also examined the composition and seasonal

patterns in fish larvae and juvenile abundance between the patchy and continuous seagrass habitats.

1.2: Problem statement

Fish larvae diversity and distribution is influenced by habitat type, seasonal variation and climatic factors (Kaunda-Arara and Mwaluma 2009). Recruitment of fish species depends on shallow water habitats following offshore spawning (MacUra *et al.*, 2016; Madi *et al.*, 2020). Shallow habitats provide food, shelter and protection for the young fish at their vulnerable life stages. However, there has been a decline in adult fish population in the water systems (Link and Watson, 2019). This decline could be attributed to increased mortality at early fish stages, juvenile and fish larvae, which depends largely on mangrove and seagrass as nurseries (Verweij *et al.*, 2006). Coastal degradation and human activities have affected the health of seagrass, causing fragmentation of seagrass (Copertino *et al.*, 2016; Htun, 2017). Previous studies have shown that patchy meadows have lower fish species richness and fish diversity in relation to continuous meadows and therefore cannot support nursery functions effectively (McCloskey and Unsworth, 2015).

Conservation of near shore habitats is an important part of fishery management. Therefore, a better understanding of how the degradation of these shallow habitats (Kimirei 2012), specifically the seagrass habitats of Watamu, affects fish larvae abundance, distribution and diversity will guide management on conservation of these habitats.

Studies along the East African Coast have concentrated on adult fishes in the seagrass habitats and mangroves (Huxham *et al.*, 2008; Kimirei *et al.*, 2011; 2012) A few studies have discussed the functions of seagrass beds (Jackson 2006) and mangroves in replenishing fish within the coral reefs (Alonso *et al.*, 2014; Almany *et al.*, 2017). Studies on fish larvae composition and diversity conducted along the Coastal Kenya investigated seasonal variation in larval assemblage, temporal variability in the Malindi Marine Park lagoon (Kaunda-Arara *et al.*, 2009; Mwaluma *et al.*, 2010; 2021). None of the above studies have interrogated the influence of seagrass bed quality as larval and juvenile habitats.

1.3: Objectives of the Study

The general objective of the study was to examine patterns in fish recruitment in Watamu seagrass habitats of varying seagrass cover, larval and juvenile abundance is related to environmental factors. The specific objectives of the study were:

1. To determine variation in fish larvae and juvenile recruitment in Watamu seagrass beds of varying seagrass cover.
2. To determine the effect of seasonal variation on fish larvae and juvenile recruitment in Watamu seagrass beds of varying seagrass cover.
3. To assess the influence of hydrographic parameters on fish larvae and juvenile recruitment in seagrass beds of varying seagrass cover.

1.4: Hypotheses

H₀₁: Seagrass cover does not influence variation in fish larvae and juvenile recruitment in seagrass beds of varying seagrass cover.

H₀₂: Seasonal variation in climatic patterns do not affect fish larvae and juvenile recruitment in seagrass beds of varying seagrass cover.

H₀₃: Hydrographic parameters do not influence fish larvae and juvenile recruitment in Watamu seagrass beds of varying seagrass cover.

CHAPTER TWO: LITERATURE REVIEW

2.1: Fishery production

Fishery production is the output of fish by humans both from capture fisheries and aquaculture (Boyd et al., 2022). Globally, the fisheries and aquaculture production reached a peak of 214 million tonnes in 2020 supporting about 600 million livelihoods wholly or partially (State of World Fisheries and Aquaculture 2022, Accessed on 31st Oct 2022).

Marine fisheries provide about 80 metric tons of protein and micronutrient-rich food for human consumption annually while contributing to approximately US\$ 3 trillion of the global economy (Barange *et al.*, 2014; FAO, 2020). It is necessary that marine resources are extracted sustainably so as to sustain the increasing human population. The sustainability in fishery service provision is dependent on ecological suitability of marine habitats, and its ability to sustain life cycles and the complex food webs (Lam *et al.*, 2020).

A functional marine ecosystem entails the interaction between the biotic and the abiotic factors (Wong-Ala *et al.*, 2018). The biotic factors, also known as the living marine resources (Dalyan *et al.*, 2021), include the producers and consumers in a marine ecosystem (Marshak and Link, 2021). Primary production begins with the production of organic materials by phytoplankton and seagrass (Daniel and Hain, 2012). The organic materials produced by phytoplankton is then consumed by zooplankton, nekton, bacteria, fungi and benthic organisms which are then preyed upon by higher organisms (Daniel and Hain, 2012), while seagrass is consumed by herbivorous.

Abiotic factors are the non-living factors that interact with biotic factors making the system sustainable. Abiotic factors that enable primary production may vary with geographic location, euphotic zones, and seasonality (Daniel and Hain, 2012). Examples of these factors are the energy from sunlight, nutrients, Carbon (both organic and inorganic) ocean currents, physical variables and chemical water variables. These factors influence the spatial and seasonal distribution of fish species, their size structure and survival (Martins *et al.*, 2015).

Abiotic factors are highly influenced by climatic patterns. The Kenyan coast experiences a monsoon cycle, a system of winds that influences the climate that reverses direction with the seasons. There are two main seasons, a cool and wet Southeast monsoon (SEM) from April to September, warm and dry Northeast monsoon (NEM) season from November to February during which these factors vary in levels and quantities based on the enabling factors (McClanahan, 1988; Mutia *et al.*, 2021). For instance, precipitation, temperature, nutrient levels and turbidity are environmental variables highly dependent on seasonality (Munk *et al.*, 2004).

Studies along the Kenyan coast show that breeding of marine fishes increases between December and January, during the NEM season due to increased temperatures (Mwaluma *et al.*, 2010; Okemwa *et al.*, 2019; Shahlapour *et al.*, 2019). Seasonal variation in larval assemblage was also noted by Mwaluma *et al.*, (2010) who reported higher densities ranging from 95–311 larvae/100 m³ during the calm NEM season, compared to 5–58 larvae/100 m³ during the SEM season. Due to the onset of climate change, there has been a rise in temperatures, and changes in seasons which has likely altered the original cycles of seasonal events (Gilliam, 2016). Therefore, it will not be surprising to find that these changes have also altered the recruitment and reproduction cycles for most fish species.

2.2: Fish recruitment

Fish recruitment is the transitioning of fish between two stages. Fish eggs hatch, undergo a pelagic larval phase, settle within nursery grounds and then develop to a juvenile stage, thus replenish fish stocks by populating recruits into a habitat (Okemwa *et al.*, 2019). For the recruitment process to occur efficiently, the habitat should be favorable, i.e. one that enhances the growth and survival of recruits (Parsons *et al.*, 2014). Such a habitat is called a nursery because it allows for growth and maturity of the early fish stages to a subadult stage before they are able to move to a permanent adult habitat (Beck *et al.*, 2001; Parsons *et al.*, 2014). Therefore, a suitable nursery is one that enables adequate interaction within the community (Beck *et al.*, 2001), and allows for connectivity between habitats (Irisson *et al.*, 2015). Such

connectivity enables colonization by juveniles or larvae and migration of subadults to adult habitats (Berkström *et al.*, 2013; Irisson *et al.*, 2015; Whitfield and Pattrick, 2015; Whitney *et al.*, 2021). The proximity of these nurseries to other habitats facilitates trophic transfers and cross-habitat utilization by fishes (Barnes *et al.*, 2012; Berkström *et al.*, 2013).

A functional nursery habitat has high density of juvenile fish, for whom adults are found offshore or in adjacent reefs (Nagelkerken *et al.*, 2008; Parsons *et al.*, 2014). Other conditions which define a suitable nursery habitat are (1) abundant supply of nutrients which supports rapid growth of larvae and juveniles; (2) habitat complexity which enhances survival of juveniles by providing hiding spaces from predators and limit movement or vision of larger predators (Beck *et al.*, 2001; Gross *et al.*, 2019; Ho *et al.*, 2018); and (3) reduced underwater visibility which reduces chances of predation of larvae and juveniles (Gullström *et al.*, 2013).

Spawning occurs offshore for most marine fish species (Brown *et al.*, 2004; Sadovy and Colin, 2012). Fish eggs hatch into larvae that are very small in size, from yolk sac and tail to a few millimeters in length. The larval stage ends when the individual metamorphoses and develops into a juvenile. Termvidchakorn and Hurtle (2013) and Rodríguez *et al.* (2017) have illustrated the main stages that a fish undergoes in a typical life cycle as presented in Figure 1 (top).

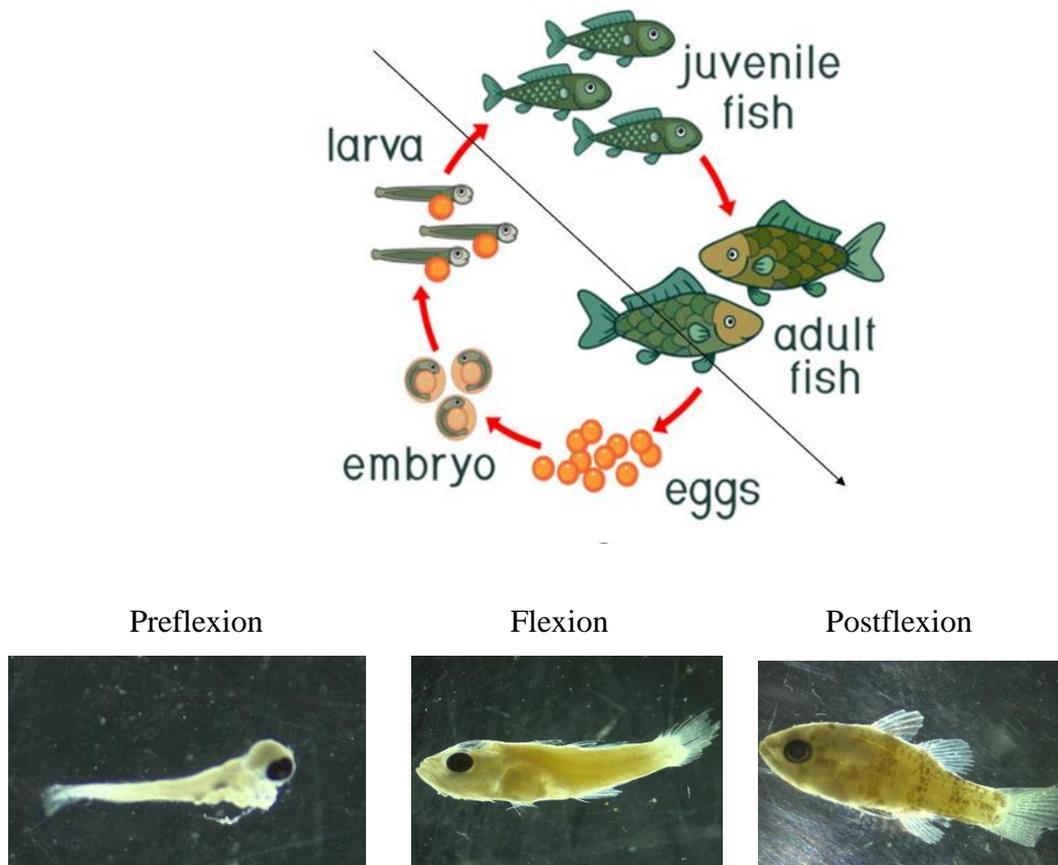


Figure 1: A diagram showing the main stages that a fish undergoes in its life cycle (top) and (bottom) the three larval stages (preflexion, flexion and postflexion), based on images of a fish larvae that belongs to family Apogonidae taken during the current study.

The first developmental phase of fish larvae is the preflexion stage which is poorly developed morphologically, unable to settle and faces high risks of mortality (Brown *et al.*, 2004). Larvae at preflexion stage swim randomly within the water column, hence termed as pelagic (Verweij *et al.*, 2006). They are drifted vertically along with plankton while trying to escape predation (Verweij *et al.*, 2006; Irisson *et al.*, 2010). It then develops to flexion stage, characterized by development of fin rays, change in body shape, developing locomotive ability and feeding techniques; before metamorphosing into postflexion stage; where complete development of fin rays occurs as well as other body structures that enable swimming (Hedberg *et al.*, 2019). At postflexion stage, they are now able to capture prey, escape predators and swim against

current (Hedberg *et al.*, 2019). In most cases larvae spend their initial stages offshore as a result of offshore spawning and probable hatching within the reef (Wong-ala *et al.*, 2018).

This explains why in some cases, larvae of dominant fishes at preflexion stage are not found near the shallow areas and seagrass beds, but are found offshore. This is a common phenomenon with families that form spawning aggregation. For example, fishes of the family Scaridae spend the first days posthatch while offshore, but settle in seagrass beds (Hedberg *et al.*, 2019).

Settlement refers to larval fish beginning to associate with structural or physical habitat, "settling" out of the water column (Camp *et al.*, 2020). During this time, larvae undergo behavioural changes that are associated with their search for an appropriate substrate and habitat (Robinson *et al.*, 2016). Once larval fish have developed enough to direct themselves, they often settle into structural habitat (seagrass, mangroves, corals, shallow areas) or aggregate into schools. Settlement marks the beginning of the recruitment period. Settlement is influenced by biotic and chemical cues. These cues vary from species to species, and range from physical cues, orientation cues and biological compounds which determine the safety of a location. The cues may be created by other individuals, by adults of the same species, or their potential predators. Larvae use these elements to tell if a location is safe for settlement (Cangialosi 2019).

One of the most favorable structurally complex habitats is seagrass beds. Post flexion larvae settle within these beds and develop to juvenile stage while benefiting from the structural protection of seagrass beds (Gullstrom *et al.*, 2012). While approaching maturity, juveniles and subadults migrate to adult habitats such as the coral reef because their bigger size cannot be supported by the shallow nursery habitats (Dorenbosch, 2006).

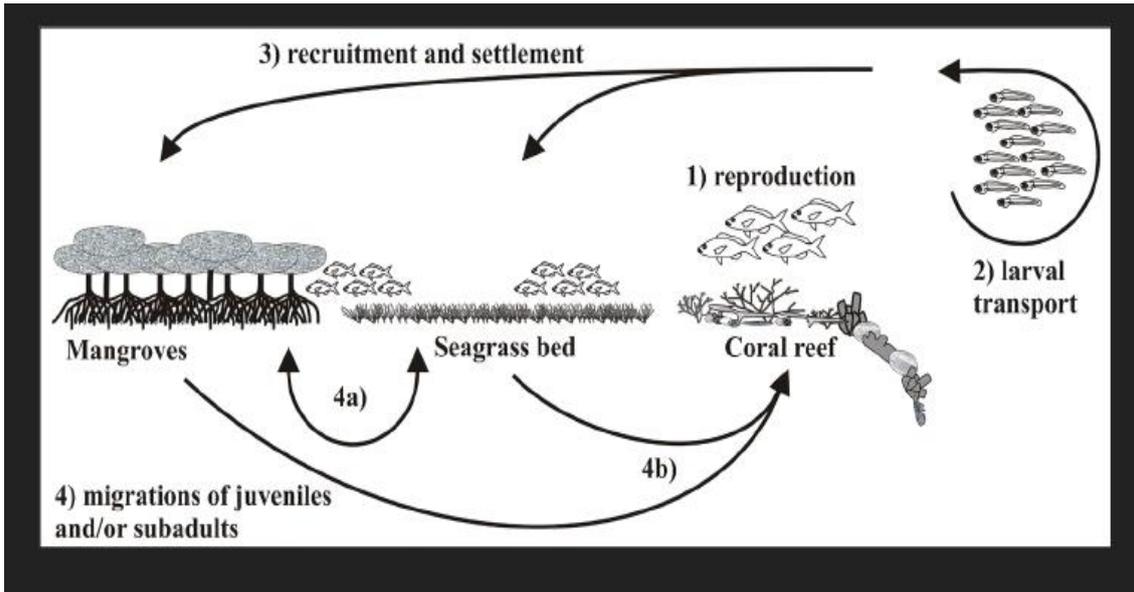


Figure 2: An illustration of ontogenetic migration and connectivity between nursery areas of mangrove and seagrass, and the deeper reef habitat (Source: Gullstrom et al., 2013).

The process where fish at specific life stages move to inhabit different habitats is called ontogenetic migration (Gullstrom *et al.*, 2013). Figure 2 illustrates the ontogenetic migration of fish species, whereby fish spawn offshore (1), the larvae hatch offshore and get transported (2) to the shallow habitats, such as the mangroves and seagrass beds. Since the shallow habitats have conditions that facilitate the role of a nursery habitats, larvae settle and develop into juveniles and subadults within the seagrass and mangrove beds (3) before migrating offshore (Berkström *et al.*, 2013). Seagrass, mangroves and corals (4a, b) have structural characteristics that favor survival of fish and recruitment. The habitat complexity, the dense shoot and intertwining of seagrass leaves and mangrove roots allow fish to hide from predation. Some fish species will alternate between seagrass beds and mangrove beds (4). The subadults then migrate to the reef, where the fish mature and the cycle starts over as new eggs are spawn (Gullstrom *et al.*, 2002; 2013).

Studies on the contribution of shallow habitats as nursery habitats have been conducted more extensively in temperate waters compared to the tropical waters, specifically within the Western Indian Ocean, the studies are scanty (Berkström *et al.*, 2013; Alonso *et al.*, 2014).

Shallow habitats, such as patch reefs (Kruse *et al.*, 2015), bays, mangrove beds, seagrass meadows, estuaries and mud flats, are said to be important nursery areas for larvae and juveniles of fish that live offshore as adults (Igulu *et al.*, 2014; McDevitt-Irwin *et al.*, 2017; Henderson *et al.*, 2019). Beaches and surf zones have also been reported to be nursery habitats in some studies (Andrades *et al.*, 2014; Martins *et al.*, 2015; Olds *et al.*, 2018).

2.3: Seagrass as nursery habitats of fishes

Seagrass are important system that contribute to fish recruitment by creating supportive conditions for other marine habitats (Cullen-Unsworth *et al.*, 2014; Alonso *et al.*, 2017). The distribution and conditions of seagrass influences distribution of associated fauna (Kane *et al.*, 2016; Alonso *et al.*, 2017). These beds attract a greater assemblage of fauna because of the high food abundance associated with the meadows, hence support rapid fish growth (McCloskey and Unsworth, 2015).

Survival of epifauna within seagrasses increases with increased habitat complexity (Copertino *et al.*, 2016; Tuntiprapas *et al.*, 2021). According to Madi *et al.* (2020) habitat complexity in seagrass beds is determined by percentage seagrass cover, shoot density and canopy height. Vegetation cover in seagrass beds can better enhance the survival of smaller fish and invertebrates as compared to unvegetated and bare habitats, by providing cover and also hindering the movement and vision of larger predators (Jaxion-harm *et al.*, 2012; Gross *et al.*, 2019). Thus, complex habitats will generally have higher fauna species richness, diversity and abundance because such habitats contain more hide spaces for prey, adequate light, and manageable water motion (Gross *et al.*, 2019; Jaxion-harm *et al.*, 2012; Alonso *et al.*, 2014; Stein *et al.*, 2014).

Seagrass habitats are facing disturbance and the cover has been declining continuously (Copertino *et al.*, 2016). Htun (2017) noted that about 60% of global seagrass populations have been degraded since 1980s. Similarly, degradation has been reported along the Kenyan Coast where nearly half of the seagrass cover in Diani Chale lagoon was destroyed through

sea urchin herbivory between the year 2001 and 2006 (Daudi *et al.*, 2013). The loss of seagrass draws concern of fisheries managers and conservationists because these are critical habitats for larvae and juveniles, and are known to take long to recover, and regain their complexity. An attempt to modify the habitat complexity of a seagrass habitat by adding artificial settling units reported an increased settling of fish, the juvenile snappers, spotty snappers and pipefish, within the study sites with additional settling units (Parsons *et al.*, 2014). In another study, a comparative investigation of fish assemblage between high seagrass covered sites and lower seagrass covered sites showed a significant decrease in diversity of associated fauna in the lower seagrass cover plots (McClockskey and Unsworth 2015). The number of species present (species richness) was also significantly higher in sites of high percentage cover while species abundance for some cryptic fishes, such as Sand Goby *Pomatoschistus minutus* Pallas 1770 (family Gobiidae) and Plaice of the family (Pleuronectidae), were lower in sites of higher seagrass cover (McClockskey and Unsworth 2015). Madi *et al.* (2020) found a higher abundance of juveniles in seagrass beds of Mayotte Island compared to adult fish within the seagrass meadows. Shannon diversity index was 2.66 and 3.31 between beds of seagrass cover of 38% and 12.7% respectively (Madi *et al.*, 2020; Simanjuntak *et al.*, 2020). However, it was also noted that variation in juvenile assemblage was influenced by water clarity, water depth and habitat complexity (Madi *et al.*, 2020). Nonetheless, most studies have reported that fish assemblage is higher in continuous habitats than in fragmented habitats (McClockskey and Unsworth 2015; Simanjuntak *et al.*, 2020).

Fish may stay within their homerange or migrate following ontogenetic dispersal, and thus utilize more than one habitat type (Green *et al.*, 2015). Honda *et al.*, (2013) reported that more than 37% of the commercial fish sampled in their study utilized seagrass and mangrove habitats in combination with coral reefs in seagrass beds of Phillipines, confirming that seagrass are favorable nursery for many reef species. Many of the species encountered exhibited ontogenetic habitat migration, especially at the onset of adult stage. A study by McClocksey and Unsworth (2015) compared faunal contribution between habitats in reference

to seagrass cover. The total number of species and Shannon-Weiner diversity was high in seagrass covers of (50-90) % ($H' = 1.35$) than in other seagrass beds (2-30) % ($H' = 0.83$). abundance and diversity of fish species collected had a positive correlation to percentage cover (McCloskey and Unsworth, 2015). Studies relating fish larvae and juvenile abundance in seagrass habitats of Western Indian Ocean region are scanty. Only one study investigated variation in fish larvae assemblage across shallow habitats of Zanzibar, Tanzania, focusing on seagrass beds of *Thalassodendron ciliatum*, in comparison to coral reefs and open water (Kimirei, 2012). The findings indicated that open-water areas accommodate high abundance of larvae (35.1 in 100 m^{-3}) than reef habitats and nearshore seagrass which recorded (13.8 and 18.5) larvae per 100 m^{-3} respectively. Fishes belonging to families Apogonidae, Blennidae and Gobiidae occurred in very high numbers throughout the nine (9) habitats studied (Hedberg *et al.*, 2017). The variation in larval abundances was attributed to differences in ocean current patterns, the state of the habitats, spawning patterns, the connectivity of habitats and over fishing. Shallow habitats like the seagrass are reported to have higher abundances of fish larvae, than reefs and open-water habitat, probably because of the hydrodynamics such as the lower current strength within the seagrass beds (Hedberg *et al.*, 2019). Seagrass beds occur in protected zones between the reef and the shore, hence strategically placed to reduce wave action, this condition is suitable for retention of larvae, mostly the pre-flexion larvae (Parsons *et al.*, 2014).

Studies on seagrass role as nursery habitats have been conducted more extensively in temperate waters, with very few studies conducted along the Western Indian Ocean region (Berkström *et al.*, 2013; Alonso *et al.*, 2014; Kruse *et al.*, 2015). Therefore, this study purposes to add knowledge on the nursery role of seagrass beds, while focusing on juvenile fish and larvae that inhabit the shallow habitats (Madi *et al.*, 2020). While most studies have applied Underwater Visual Census in assessing juvenile abundance (Kimirei *et al.*, 2011; Igulu *et al.*, 2014; Okemwa *et al.*, 2019), the present study used beach seining because of its ease of use in shallow systems as noted by Dembkowski *et al.* (2012).

Moreover, this study focused on estimating abundances for which seining has been recommended (Hahn *et al.*, 1984). Most studies along the East African Coast have looked at abundance of adult fishes in the seagrass and mangroves habitats (Wainaina *et al.*, 2010; Kimirei *et al.*, 2013; Tano *et al.*, 2017). Others related the use of seagrass beds and mangroves in replenishing coral reef fishes (Dorenbosch, 2006), but none have looked at both larvae and juveniles while examining conditions and habitat complexes that favor them (Lugendo, 2007; Kimirei *et al.*, 2011; Alonso *et al.*, 2014).

CHAPTER THREE: MATERIALS AND METHODS

3.1: Study area

This study was conducted in the intertidal waters of Watamu Marine Reserve in North-Coast region of Kenya adjacent to the Watamu Marine National Park. Figure 3 shows a map of the study area, with two sampling sites, located within the shallow lagoons of Watamu namely: Watamu Blue Lagoon (Site 1) and Watamu Beach (Site 2). Both sites have a uniform low topography dominated by a mosaic of seagrass beds interspersed with varying seagrass cover (Mwaluma *et al.*, 2010). The vegetation at Watamu Blue Lagoon (Site 1) was composed of seagrass that is relatively continuous with seagrass cover of 65.49%. The dominant seagrass species are *Thalassodendron ciliatum* (Forsskål) which has average cover of 34 %. Watamu Beach (Site 2) had a seagrass cover of 62.08 %. The dominant seagrass species in this site are *T. ciliatum*, *Cymodocea rotundata* and *Halodule uninervis* which cover an average of 18 %, 17 % and 11 % respectively. Site 2 consisted of mixed meadows comprising pioneer species that may have been as a result of previous reported urchin herbivory that had severely affected the region as evidence of stumps seen during this study. Evidence from satellite data has also shown massive degradation and decrease of seagrass cover over the last decade (Ngisiange *et al.*, unpublished data, see Appendix 1). The satellite data indicates that there has been a constant decline in seagrass cover between 2009 and 2019, with a single peak of increased cover in the year 2002. The tidal cycle at both sites is mixed semidiurnal with two maxima and two minima per day with a tidal range of about 2.0 at the neap tide and 2.9 during spring tide (Mwaluma *et al.*, 2011).

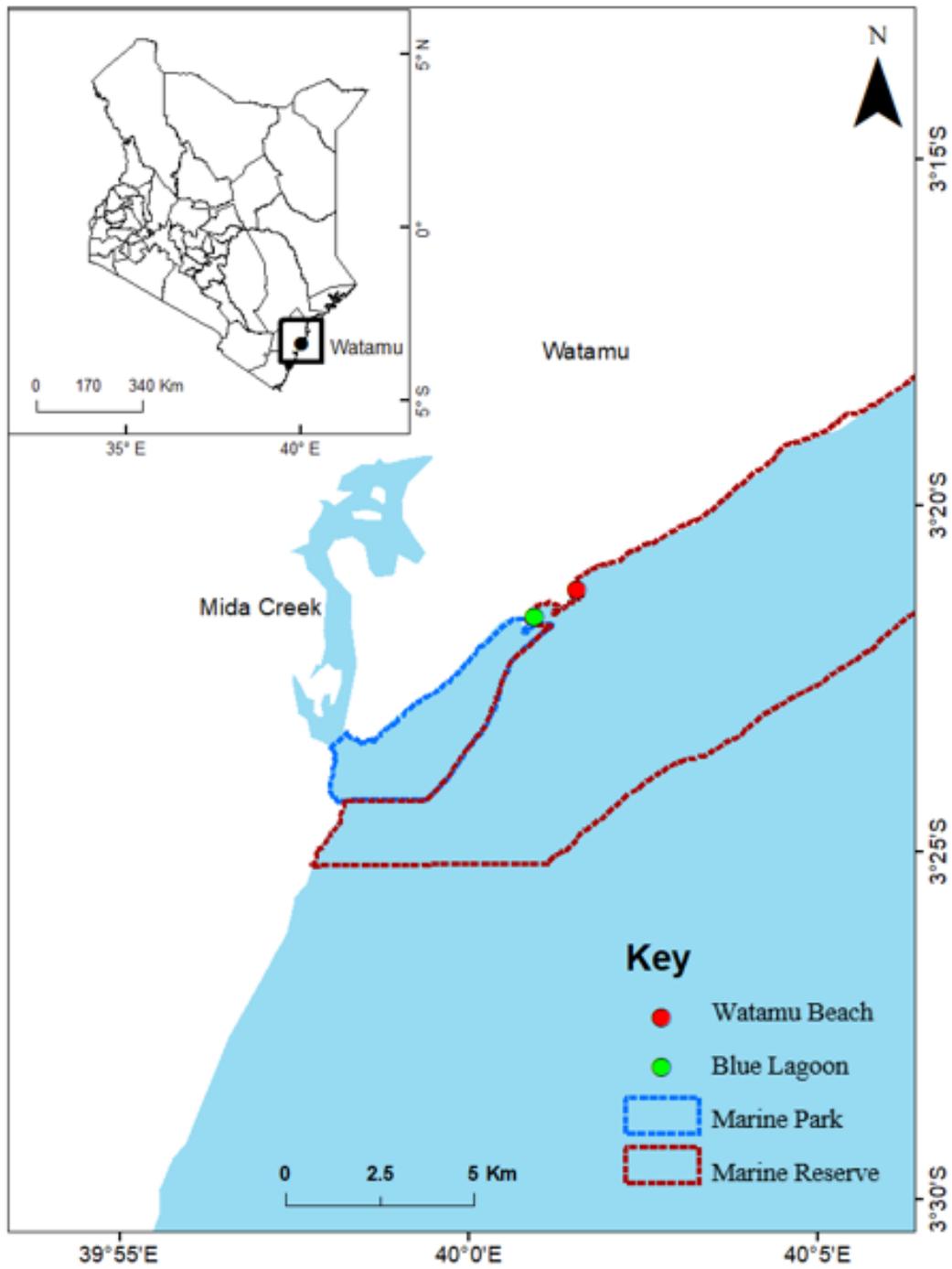


Figure 3: A map showing the location of study sites: Site 1 (Watamu Blue Lagoon) and Site 2 (Watamu Beach)

3.2: Study design

Sampling was done once every month during the southeast monsoon (SEM) months (June, July, August) and northeast monsoon (NEM) months (November, December, January) of 2019/2020 and 2020/2021. Hydrographic parameters, fish larvae and juvenile were sampled at each sampling occasion as detailed below.

3.3: Estimation of seagrass cover

Square quadrats were used to assessing seagrass cover. Sampling was performed using 25 x 25 cm quadrats which were randomly cast at the study sites. Using underwater snorkeling gear, seagrass species present within the quadrats were identified and percentage coverage of seagrass species, bare ground and sand estimated following the procedure described in Short and Duarte (2001).

3.4: Determination of hydrographic parameters

Water quality parameters of interest were temperature, salinity and Chlorophyll-*a*. Water temperature and salinity were measured *in-situ* using YSI ProDigital Sampling System Multi-parameter probe. These parameters were measured once every month while collecting the fish larvae and juvenile samples.

For Chlorophyll-*a* analysis, five (5) litres of seawater were collected at each site and filtered through 47 nm GFF filters pore size and the filtrate used for extraction of chlorophyll-*a*. Water sampled for chlorophyll-*a* analysis was placed in dark sampling bottles. In the laboratory, the water was filtered using 47 nm GFF filters of pore size and the filtrate used in the extraction of chlorophyll-*a*. Acetone was added to the filtrate, in quantities of 10 ml, and left overnight for the extraction process to take place. The contents were then centrifuged at 4000 revolutions per min for 10 minutes in a centrifuge machine (Julabo-lanofuge centrifuge). The absorbance was measured using a spectrophotometer UV-VIS10[®] spectrophotometer at wavelength 650 nanometre, and corrected at wavelength 660 nanometer (Warren 2008).

A 90% acetone solution was used as a blank. The formula used to quantify Chlorophyll-*a* is as given in standard operating procedures (WVDEP, 2018)

$$\text{Chlorophyll-}a \text{ (}\mu\text{g/ml)} = 12.7 (A_{660}) - 2.69 (A_{650})$$

3.5: Sampling for fish larvae

Fish larvae were sampled using procedures, for zooplankton and ichthyoplankton sample collection as recommended by Wiebe and Benfield (2003). It involved using a conical-shaped plankton net of 500 μm mesh size and a mouth area of 0.2 m². A General Oceanics flowmeter was installed at the center of the nets mouth opening to allow estimation of the volume filtered.

Samples were collected by towing a two-meter-long conical-shaped plankton net of 500 μm mesh size and a mouth area of 0.2 m², behind a boat at a speed of about 1m/s for 20 minutes, as shown in Figure 4 (a). Horizontal tows were made on the subsurface water, 1-3 meters deep. As the water is filtered out of the net, the samples are collecting in the collection chamber as shown in Figure 4 (b). The net collects both zooplankton and ichthyoplankton. After 20 minutes of towing, the net was lifted from the water and splashed with sea water, so that all the organisms are washed down into the collection chamber that is attached to the bottom of the plankton net (Figure 4b and c). The concentrated sample is placed on a 250-micron sieve for cleaning and removal of large debris while retaining the sample. The sample is then transferred to a sample bottle for storage. Collected samples are preserved in 5% formaldehyde buffered in seawater (Figure 4 d), which is then transported to the laboratory for pre-analysis and identification. At each site, two replicate tows were made at each sampling site, once each month during flood tide.

(a)



(b)



(c)



(d)



Figure 4: A step-wise illustration of field procedures: (a) towing plankton nets behind the boat, (b) collection of filtered samples into a chamber attached to plankton net, (c) sieving and cleaning of samples, and (d) a labelled field sample for laboratory analysis.

3.6: Identification of fish larvae

In the laboratory, fish larvae were manually isolated from the zooplankton, as observed under a Zeiss Stemi 305 stereo microscope. Fish larvae were selected based on presence of large eyes, elongate non-segmented body, jaws and fins. This is the criteria used in differentiating other zooplankton from fish larvae (Slotwinski et al., 2014).

Fish larvae were then identified to the lowest taxa possible using keys by Leis and Rennis (1983), Leis and Trnski (1989), Mwaluma et al., (2014), Leis and Carson-Ewart (2000). The total length, defined as the measurement taken from the anterior-most part of the fish to the end of the caudal fin rays (Anderson and Gutreuter 1983) of individual larvae was measured to the nearest 0.1 mm and recorded. Density of larvae was expressed as number of larvae per 100 m⁻³. Their developmental stage was also determined as either preflexion, flexion or postflexion as described by Mwaluma et al., (2014). Preflexion larvae is the post hatch stage that begins by egg yolk absorption and ends at the start of upward flexion of the notochord. Flexion larval stage is marked by the beginning of flexion of the notochord, development of the caudal fin and fin rays in majority of species, development of supporting bones and cartilages of the homocercal fin. The postflexion larval stage is determined by the formation of the caudal fin (distal margin of the hypural elements vertical) to attainment of full external meristic complements such as fin rays and myomeres.

Zooplankton are the organisms with diverse animal-like features, ranging in size from a few micrometers in length to 5 millimeters in length. Their physical characteristics are diverse, including those that form hard jointed exoskeleton (Crustaceans), those that are worm-like (Annelida) or tadpole-like (Chordata); soft and jelly-like (Cnidaria), triangular shape with cilia (Bryozoa). Some are shell-like (Gastropoda or Bivalve). The major difference between most zooplankton and fish larvae is that fish larvae is not segmented and has distinct large eyes, jaws and fins (Figure 5 a, b and c) (Slotwinski et al., 2014).

Therefore, in quantification of zooplankton, after isolating fish larvae the remaining zooplankton were counted in subsamples of 20 ml per diluted volume of 250 ml. Total count per subsample was used to estimate abundance of zooplankton per Liter of seawater.

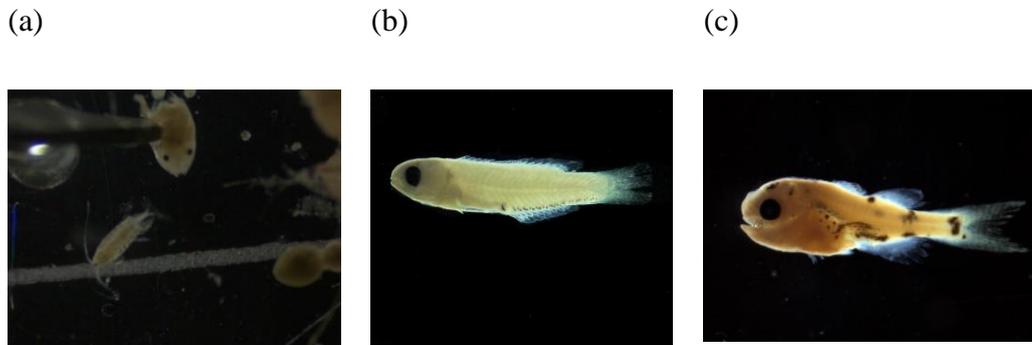


Figure 5: Images of (a) zooplankton, (b) fish larvae of family Scaridae (c) fish larvae of family Apogonidae, as seen under the dissecting microscope

3.7: Sampling for juvenile fish

In this study a beach seine was used for sampling juvenile fish as it was considered effective in sampling relatively shallow water, and effective in estimation of relative abundance (Hahn *et al.*, 2007). At both sites, juvenile fish were sampled using a beach seine net measuring 4 m in length, 2.5 m in height, and 1.5 cm mesh size. The sampled area was approximately 250 m². The area was determined by measuring length (50 m) and width (50 m), using a tape and marked with buoys. At each site, eight replicate samplings were randomly conducted within the measured perimeter. Sampling was done during spring low tide in the SEM months of July and August 2019/2020, and June, July, and August 2020/2021, and the NEM months (November, December, January) of 2019/2020 and 2020/2021.

The beach seine net was laid perpendicular to the shore by two fishers wading in the water on foot. The seine net was hauled towards the shore through a 90-degree arc against the current. Two other fishers assisted in lifting the net and collecting the fish catch after hauling. The same fishers conducted the seining throughout the study period. The operation ranged between 20-30 minutes for a single haul (Figure 6a).

The fish species was recorded and the total length for each specimen was measured to the nearest 0.1 cm on a standard fish length measuring board before being preserved in absolute alcohol. The fish that were not identified at the site were coded and preserved for identification in the laboratory using Anam and Mostrada (2012), Heemstra and Smith (1986) and Lieske and Myers (2004) (Figure 6b).



Figure 6: Photographs showing (a) field sampling of juveniles (seining) for juvenile fish and (b) a sample of juvenile caught.

The fish catch was sorted and categorised as (i) juveniles if their length was less or equal to the minimum age at maturity, as reported in FishBase (Froese and Pauly 2023) and (ii) if their sizes were $<25\%$ of maximum total length of the adult fish (Okemwa *et al.*, 2019).

3.8: Data analyses

Measurements of all tested variables were computed and analyzed using STATISTICA, a data analysis software. Total number of larvae in the sites were converted to density or larval abundance (larvae/100 m³). Shannon diversity index (H), taxonomic richness, and Pielou's evenness index (J) were used to assess abundance and assemblage structure of fish larvae in the sites where sampled, using the formulas below.

Pielous's index (J') of evenness

$$J' = H' / \log(S), \text{ (Pielous, 1966);}$$

Where

H' is the number derived from the Shannon diversity index

S is the number of species in the sample

Shannon-Wiener diversity index (H');

$$H' = - \sum (p_i \log p_i) / N \text{ (Shannon and Weiner, 1963)}$$

Where

n is the number of species in a sample,

p_i is the number of individuals in a species and

N is the total number of individuals in a sample

Diversity index considers the number and evenness of the species. It increases either by having additional unique species or greater species evenness

Margalef's species richness index, (D)

$$D = S - \log_{10} N \text{ (Margalef 1968)}$$

Where

S is the number of species in the sample

N is the sample size

Species richness measures relative wealth of species in the community.

Comparison of larval abundance between the two sites and between the two seasons is one of the objectives in the current statistical analysis. A pairwise analysis of variance was used to evaluate the impact of site (Pristine and Degraded) and seasons (NEM and SEM) on larval abundance.

Effect of hydrographic parameters on fish larvae abundance were assessed by subjecting them to correlation analysis, then comparison made between sampling sites and seasons by pairwise analysis of variance (ANOVA). Spatial patterns in fish larvae assemblage structure was investigated using a nonmetric multidimensional scaling.

Hydrographic parameters and fish density were subjected to t-test to evaluate differences in pH, salinity, chlorophyll a, temperature, DO and fish larvae and juveniles density. Analysis of variance (ANOVA) was used to determine significant differences between season, site and the hydrographic parameters.

Univariate analysis: Prior to analysis, fish larvae and juvenile density data were log transformed ($\log_{10} x+1$) to fulfill the normality of data requirements in parametric statistical analysis (Rodriguez and Vieira 2013). Shannon-Weiner diversity (H), Pielou's index of evenness (J) and Margalef's index of richness (d) were applied, to assess community structure or biodiversity (Oksanen *et al.*, 2020), calculated using the R software Version 2.5-6 and Vegan package (R Studio Team 2015).

To determine differences in fish larvae abundances between sites and seasons a Pairwise ANOVA was applied (Wainaina *et al.*, 2013; Chande *et al.*, 2019).

Multivariate analysis of larvae: Community analysis was assessed by ordination using Non-Metric Dimensional Scaling (nMDS) clusters for the two seasons, for both larvae and juveniles. To ascertain the effect of hydrographic parameters on fish larvae density stepwise generalized linear regression models were used to get the correlation coefficients on the interaction between fish larvae abundance and hydrographic parameters. Larval abundance was compared against temperature, salinity, zooplankton abundance and chlorophyll-*a*, while fish juvenile abundance was compared against temperature, salinity and chlorophyll-*a* (Marin 2016). All statistical analyses were done using the R software Version 2.5-6 and Vegan package. Significance was determined at $p = 0.05$.

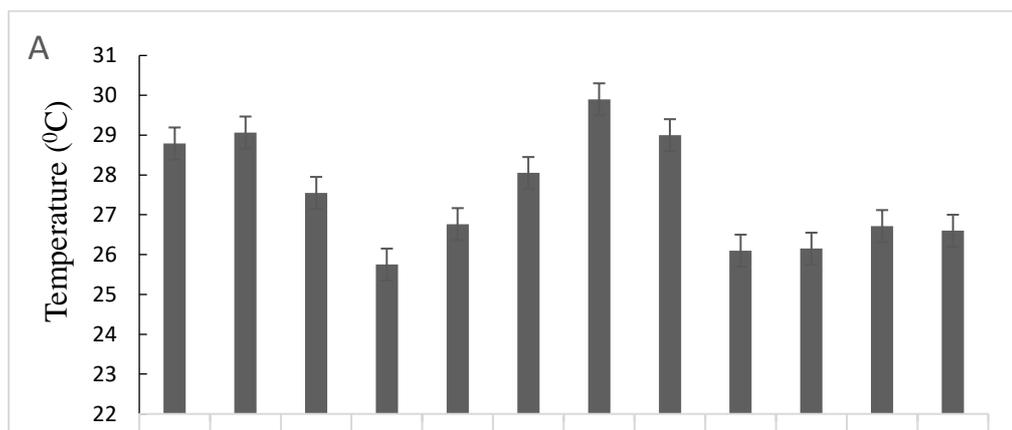
Multivariate analysis of juvenile density: Juvenile fish abundance was compared using PERMANOVA to test for differences between sites, months, and years. Community analysis was assessed using Non-Metric Dimensional Scaling (nMDS) clusters. To ascertain the effect of hydrographic factors on juvenile fish, stepwise generalized linear regression models (GLM) were used to obtain the correlation coefficients on the interaction between juvenile abundance against temperature, salinity, and Chlorophyll-a (Marin 2016).

CHAPTER FOUR: RESULTS

4.1: Hydrographic parameters

The hydrographic parameters varied between months and seasons. Figure 7A, B and C show the monthly mean values for temperature, salinity and chlorophyll-*a* respectively as determined during the study. Chlorophyll-*a* was highest during the SEM season especially in June 2019 (2.7 mg/L) compared to the NEM (0.7 mg/L) and indicated an inter-annual variability (Figure 7C). The average salinity and temperature similarly varied between the four seasons with lowest salinities (33.8 ± 0.04 ppt) recorded in SEM/2020 and temperatures (26.1 ± 0.30 °C) recorded during NEM/2019 (Figure 7B).

Temperature varied significantly between the months ($p < 0.05$), seasons ($p < 0.005$) and years ($p = 0.05$, Figure 7A). Similarly, Chlorophyll-*a* showed significant variation between months ($p < 0.005$) and the years ($p < 0.005$) but no significant variation between seasons and sites, Figure 7C). Salinity on the other hand showed no significant variation between the sites, months, season and year (Figure 7B).



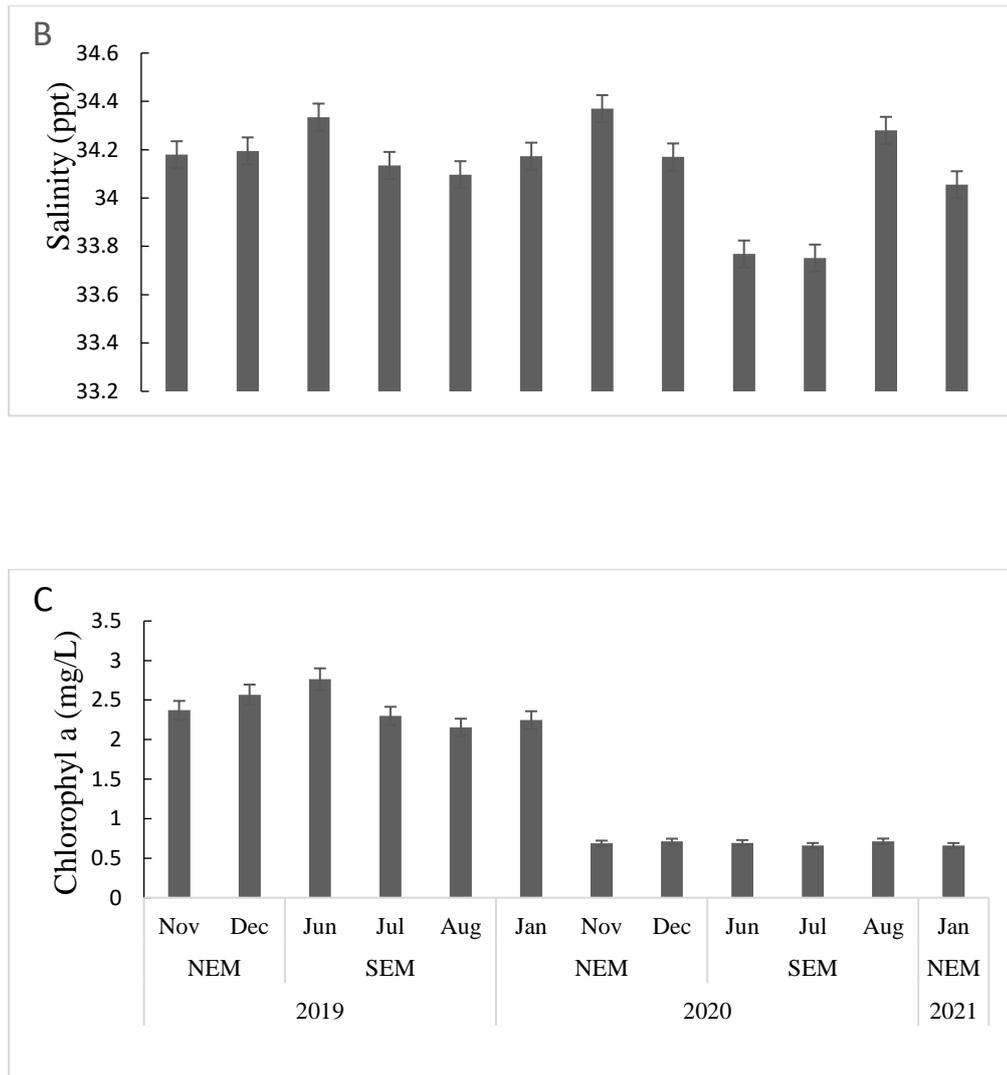


Figure 7: Monthly and seasonal variation in (A) temperature, (B) salinity, and (C) Chlorophyll-*a*.

4.2.1: Fish larvae taxonomic composition

Fish larvae sampled from the two sites belonged to 35 families and 38 species in total, with 19 families and 33 species sampled from site 1 and 18 families and 36 species sampled from site 2 (Table 1). Fish larvae belonging to families Lethrinidae, Lutjanidae, Ostraciidae, Serranidae were sampled in Site 1 but were absent in Site 2 samples. Fish larvae belonging to families Atherinidae, Exocoetidae, Lethrinidae, Nomeidae, Platycephalidae, Pomacentridae were only present in Site 2.

Table 1: Taxa composition, density (per 100 m³) and development stages (Pre-preflexion, Postflexion, Fle-flexion) of larvae from Watamu Beach (Site2) and Blue Lagoon (Site 1) during SEM (Southeast monsoon) and NEM (Northeast monsoon) seasons

Family	Species	Devt stage	Abundance (per 100 m3)			
			Blue Lagoon		Watamu Beach	
			NEM	SEM	NEM	SEM
Acanthuridae	-	Po	2.			
Apogonidae	<i>Apogon sp.</i>	Po	8			1
	<i>Gymnapogon</i>	Po	8	3		
	<i>Pseudamine apogon</i>	Pre				1
Atherinidae	<i>Hypoatherina</i>	Pre	8			
Atherinidae	-	Pre, Po	5.1		1	
Blenniidae	<i>Blennid sp.</i>	Pre		6		
	<i>Petrocirtes mitratus</i>	Po	10	2	7	3
	<i>Petroscistes breviceps</i>			1		
Blenniidae	-	Pre, Fle, Po	30	1	8	
Callionymidae	-	Pre, Fle, Po	2			
Diodontidae	-	Po			1	
Engraulididae	<i>Stolephorus commersonii</i>	Fle, Po		1		
	-	Fle	1		18	
Exocoetidae	<i>Cheilopogon sp.</i>	Po	8			

Gerreidae	<i>Gerres sp</i>	Fle		1		
	-	Fle	1		1	
Gobiidae	<i>Gobid sp</i>	Pre, Fle,		2		12
		Po				
	-	Pre, Fle,	46	3	72	2
		Po				
Istiophoridae	-	Pre			16	
Labridae	<i>Cheilinus sp</i>	Po	8	1	8	
	<i>Cheilinus</i>	Fle, Po	8	2		
	<i>oxycephalus</i>					
	<i>Cheilio inermis</i>	Po	8	1		0.47
	<i>Coris frerei</i>	Po		1		
	<i>Halichoeres sp.</i>	Po		1		
	<i>Paracheilinus sp.</i>	Po			8	
	<i>Pseudochelinus</i>	Fle				1
Labridae	-	Fle	4		7	
Leiognathidae	-	Pre			1	
Lethrinidae	-	Fle	1			
Lutjanidae	<i>L. kasmira</i>	Po			1	
Lutjanidae	-	Fle	1		1	
Monodactylidae	<i>Monadactylus sp.</i>	Pre, Fle		5		
	<i>Monodactylus</i>	Fle			8	
	<i>argenteus</i>					
Myctophidae	-	Pre	49		16	
Nemipteridae	<i>Nemipterid sp.</i>	Pre		1		2
		Pre	49		2	
Nomeidae	<i>Cubiceps sp</i>	Pre	8.	1		

Ostraciidae	<i>Lactoria diaphana</i>	Pre, Po				2
	<i>Ostracion sp.</i>	Pre				5.
Platycephalidae	<i>Papilloculiceps</i>	Po		4		
	<i>longiceps</i>					
	<i>Platicephalid sp.</i>	Fle		1		
	-	Fle			8	
Pomacentridae	<i>Abudefduf</i>	Po	1			
	-	Fle	2			
Scaridae	<i>Calatomus sp.</i>	Pre, Po	16	2		11
	<i>Leptoscarus</i>	Po	16	5		1
	<i>vaigiensis</i>					
	<i>Scarus sordidus</i>	Po				
	<i>Scarus sp.</i>	Po		1	8	
	-	Po	7		2	
Scorpaenidae	<i>Scorpaenodes</i>	Po		2		
	<i>Synanceia</i>	Po				5
	-	Pre			1	
Serranidae	<i>Anthias sp.</i>	Pre			16	
	<i>Serranid sp.</i>	Pre				1
Solenostomidae	-	Fle, Po	2		1	8
Sphyraenidae	-	Po			1	
Syngnathidae	<i>Hippocampus sp</i>	Fle, Po		1		1
	<i>Syngnathus sp.</i>	Fle	8			
	-	Pre, Fle, Po			26	
Unidentified	Unidentified	Pre, Fle	18	1	17	2

Fish belonging to family Labridae represented the highest number of identified species compared to the rest, a total of 8 species namely *Cheilinus sp.*, *Cheilinus oxycephalus*, *Cheilio inermis*, *Coris frerei*, *Halichoeres sp.*, *Paracheilinus sp.*, *Pseudochelinus sp.* and *Labrid spp.* Scaridae (*Calatomus*, *Leptoscarus vaigiensis*, *Scarus sordidus*, *Scarus sp.*) and Apogonidae (*Apogon sp.*, *Gymnapogon sp.* and *Pseudamine apogon*) also had a high number of species represented (See Appendix 3 for images of larvae). Rare fish belonging to families Diodontidae, Acanthuridae were sampled at Site 2. Some fish larvae (38.98 larvae/100m³) could not be assigned family names or species names hence classified as Unidentified species. Most of the unidentified larvae were disfigured due to mishandling during pre-processing and lost features that assist in identification.

4.2.2: Fish larvae abundance

Figure 8 displays the abundance of fish larvae sampled at the two sites. The most dominant fish belonged to families Gobiidae (Site 1= 49 and Site 2= 90 larvae/m³), followed by Scaridae (Site 1= 48, Site 2=22). and Blenniidae (Site 1= 50, Site 2=18). the least abundant were Sphyraenidae and Diodontidae (Table 1). Fish belonging to families Gobiidae, Syngnathidae and Engraulidae were dominant at Watamu Beach while Scaridae, Blenniidae, Myctophidae dominated the Blue Lagoon.

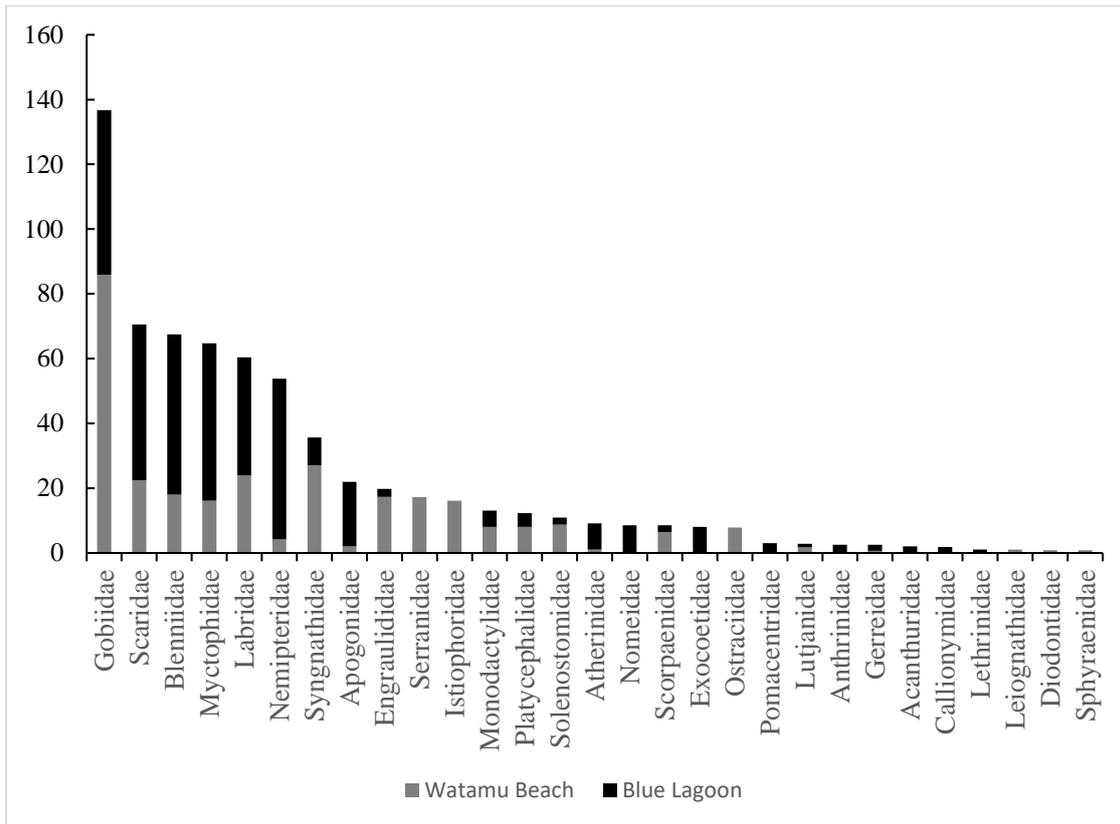


Figure 8: Relative abundance of the dominant fish larvae sampled at Watamu Beach (Grey bars) and Blue Lagoon (Black bars)

4.2.3: Development stage of fish larvae

All the three larval stages were present from samples of larvae belonging to families Gobiidae, Blenniidae Callionymidae and Syngnathidae. Only one stage of the larvae was sampled in some of the fish families. For example, larvae of fish belonging to families Atheriniridae, Istiophoridae, Leiognathidae, Nemipteridae and Serranidae were encountered at preflexion stage; larvae belonging to families Gerreidae, Labridae, Lethrinidae were encountered at flexion stage; while those belonging to families Acanthuridae, Exocoetidae, Sphyraenidae were sampled at postflexion stage.

Figure 9 shows the monthly distribution patterns of larval stages. The Blue Lagoon had the highest average relative abundance of postflexion larvae.

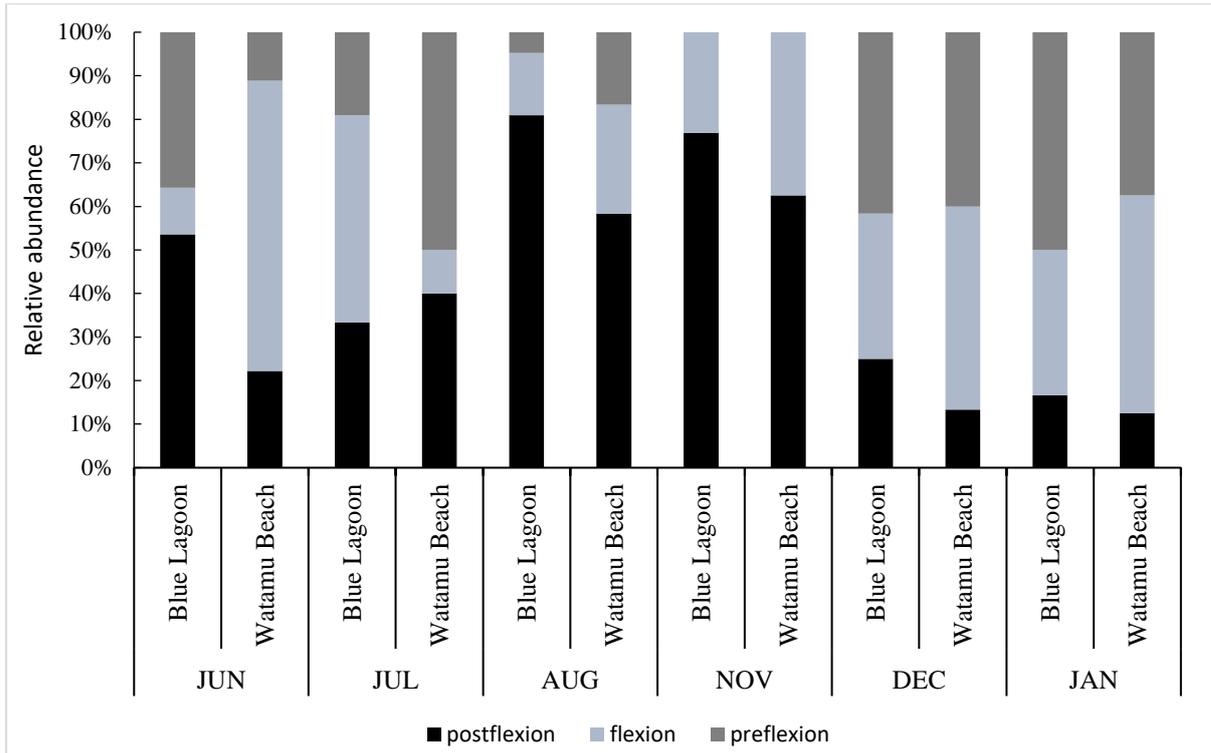


Figure 9: Mean monthly relative abundance of fish larvae development stages for fish sampled in Watamu Beach and Blue Lagoon (black bars-postflexion, light grey-flexion, pre-preflexion).

The numbers of postflexion larvae increased as the Southeast monsoon season advanced. Preflexion larvae were higher in the northeast monsoon season. Preflexion larvae were not encountered in the month of November. 53.5% of larvae were collected during NEM. Majority of larvae sampled were at postflexion stage, the stage at which larvae transition to juveniles. 60% of larvae sampled during SEM and 42% sampled during NEM were at postflexion stage.

4.2.4: Fish larval abundance

Mean monthly larval abundance recorded during the study are presented in Figure 10. The highest monthly larval abundance was recorded in November 2019, with an average of 8.09 ± 0.46 and 12.14 ± 0.27 larvae per 100 m^3 , sampled at Blue Lagoon and Watamu Beach respectively (Figure 10). Larval abundance did not show a significant difference between Site 1 and Site 2 ($p = 0.94$), neither but varied significantly between months ($p = 0.003$) and

between seasons ($p = 0.045$). A higher total abundance was observed in Site 1 (385.40 larvae per 100 m^3) than in Site 2 (315.45 larvae per 100 m^3), with more larvae sampled during NEM (589.72 larvae per 100 m^3) than in SEM (111.13 larvae per 100 m^3).

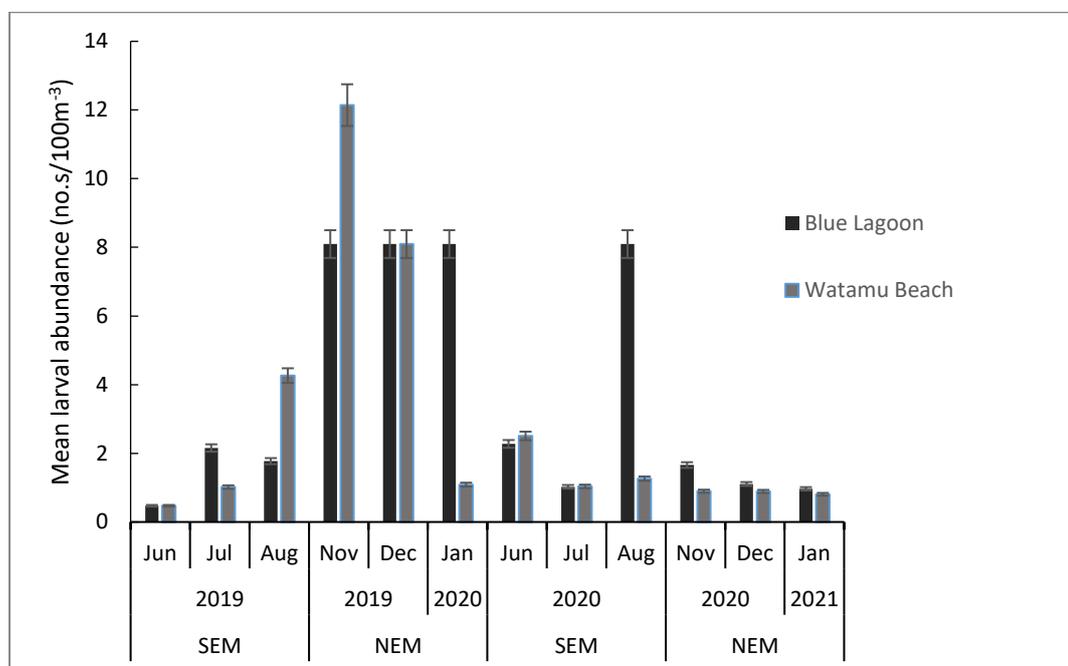


Figure 10: Monthly variation (mean \pm SE) in larval abundance (numbers per 100m^3) in the two sites, Site 1 (Blue Lagoon- black bars) and Site 1 (Watamu Beach-grey bars)

Fish belonging to Families Labridae (Site1= 19 larvae per 100 m^3 , Site 2 = 32 larvae per 100 m^3) and Scaridae (Site 1 = 15 larvae per 100 m^3 , Site 2=23 larvae per 100 m^3) had higher abundance (See Table 1). Gobiidae (117.54 larvae per 100 m^3), Myctophyidae (64.76 larvae per 100 m^3) were more abundant in NEM than in SEM. NEM (589.72 larvae per 100 m^3) generally had higher total larval abundance than SEM (111.13 larvae per 100 m^3).

4.2.5: Fish larval diversity

Diversity (H') did not vary significantly between the two sites ($p = 0.223$), although the Watamu Beach site generally had higher diversity (0.8 ± 0.15) than the Blue Lagoon (1.91 ± 0.11). An inter-annual variation in larval diversity was also observed, though not significantly different ($p = 0.56$). The families were more diverse in year 2 ($H' = 0.33$) than in year 1 ($H' = 0.29$). Higher diversity was observed at the Blue Lagoon in the month of June 2019

($H' = 0.86$), whereas in the Blue Lagoon the highest diversity was noted in December 2019 ($H' = 1.91$).

Figure 11 shows the seasonal variation in fish larval (A) Evenness and (B) Richness for both the Watamu Beach and the Blue Lagoon, for SEM and NEM. Larval evenness (J) showed no significant variation between the Blue Lagoon (0.66 ± 0.094) and Watamu Beach (0.87 ± 0.086 , $p = 0.29$). The taxonomic richness showed no significant difference between the Blue Lagoon ($S = 3.667 \pm 0.34$) and the Watamu Beach ($S = 3.65 \pm 0.57$, $p = 0.29$), neither was variation between the months ($p > 0.05$) and seasons ($p > 0.05$) significant (See Appendix 5B).

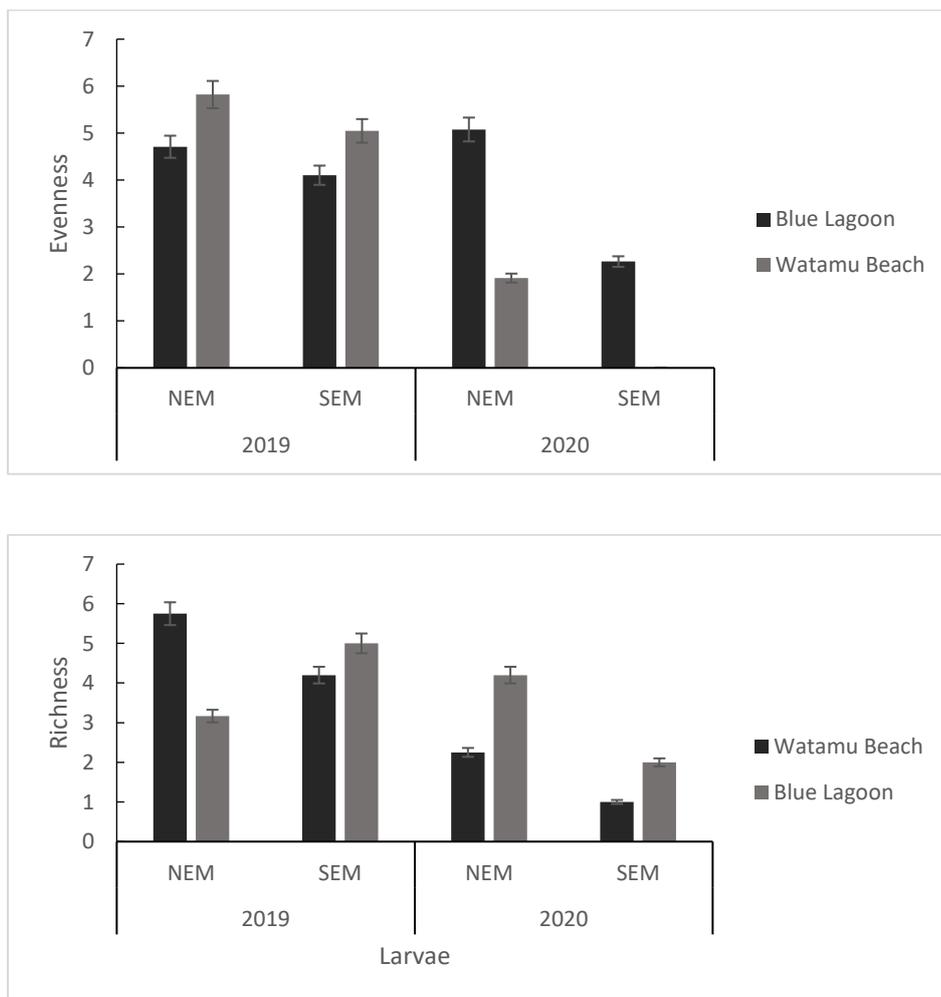
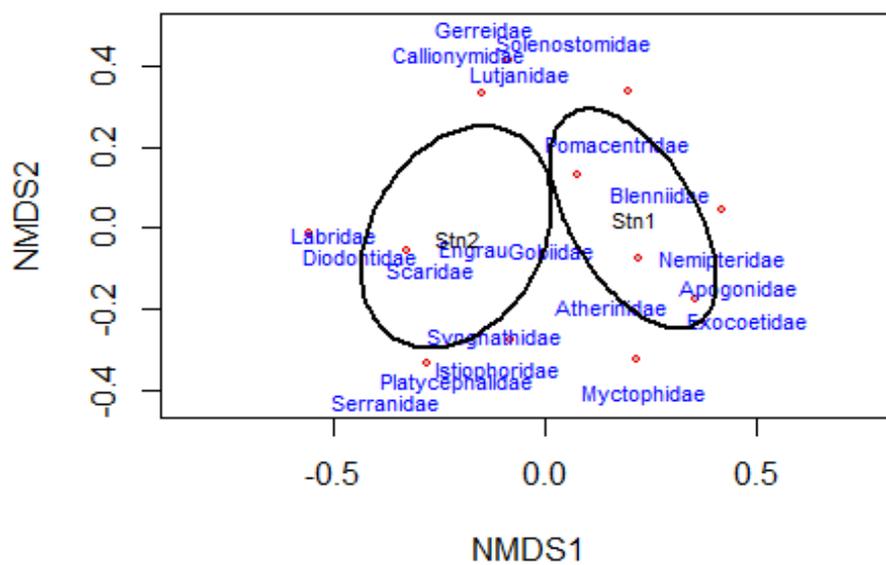


Figure 11: Seasonal variation in fish larval (A) Evenness and (B) Richness for both the Watamu Beach (black bars) and the Blue Lagoon (grey bars), for the two seasons SEM and NEM.

4.3: Effect of seasonal variation on fish larvae abundance

The overall larval abundance was higher during the NEM than SEM, varying significantly between seasons ($p < 0.05$). Tukey HSD identified a higher abundance in the NEM specifically in the month of November, and in the second SEM. Fish larvae families associated with particular sites during both seasons of the monsoons (Figure 12).

(A) Stress = 0.17



(B) Stress = 0.10

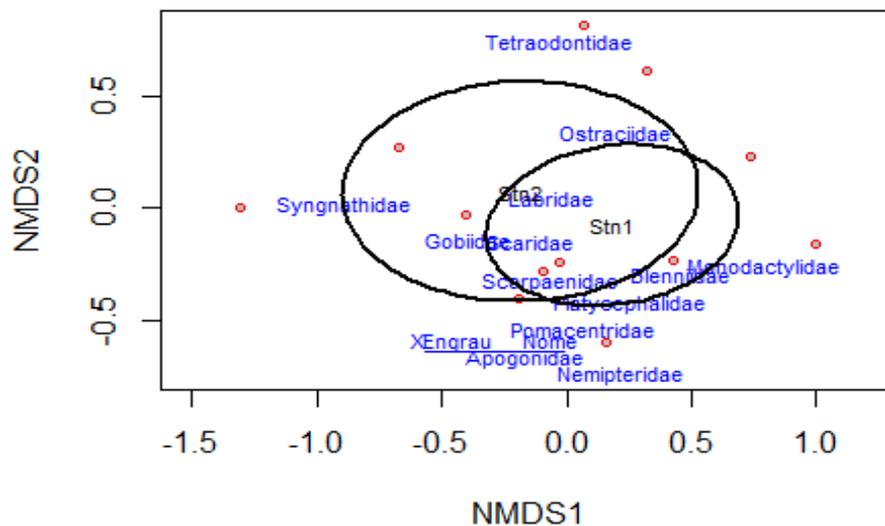


Figure 12: ordination chart showing the abundance of dominant larval families sampled during NEM (A) and SEM (B) (Engrau-Engraulididae, Nome-Nameidae) and their correlation with Site 1 (Blue Lagoon) and Site 2 (Watamu Beach).

During the NEM season (A) Pomacentridae, Blenniidae, Nemipteridae, Apogonidae and Atherinidae were associated with the Blue Lagoon while Engraulididae, Scaridae Gobiidae, Labridae and Diodontidae closely associated with the Watamu Beach. Gerreidae, Solenostomidae, Callionymidae and Lutjanidae appeared outside the ellipses but correlated with both sites. During SEM (B), preference to habitats overlapped with Labridae, Gobiidae, Scaridae, Scorpaenidae, Blenniidae and Platycephalidae being associated with both sites. Pomacentridae, Engraulididae, Nemipteridae, Apogonidae, occurred outside the ellipses but are corelating with both sites.

4.4: Effects of hydrographic parameters on fish larvae abundance

Table 2 describes the correlation of hydrographic variables on fish larval abundance. Zooplankton abundance and Chlorophyll-*a* correlated positively and significantly ($p < 0.05$) with abundance of larvae while, temperature and salinity were correlated negatively with abundance of larvae ($p > 0.05$), whereas seagrass cover correlated positively with larval abundance.

Table 2: Correlation coefficients between hydrographic properties and larval abundance

	Correlation Coefficient	p -value
Temperature	-1.707	$p > 0.05$
Salinity	-0.323	$p > 0.05$
Chlorophyll- <i>a</i>	2.359	* $p < 0.001$ ***
Zooplankton abundance	2.359	* $p < 0.001$ ***
Seagrass cover	0.0025	$p > 0.05$

*p depicts highly significant difference

4.5.1: Juvenile fish taxonomic composition and abundance

Table 3 shows the juvenile taxa composition and abundance. In total of 41 species from 28 families were identified from a total of 659 fish sampled over the study period. Dominant families were Lutjanidae, and Siganidae, which were 15.5 %, and 12.9 % of total fish caught respectively.

Table 3. Taxa composition, abundance (numbers), size (mm) of fish juvenile, from Blue Lagoon and Watamu Beach

Taxa	Blue Lagoon		Watamu Beach	
	Abundance (no.s)	Size/ Size range (cm)	Abundance (no.s)	Size/ Size range (cm)
Acanthuridae			2	
<i>Acanthurus auranticavus</i> (Randall, 1956)	1	6.3	0	
<i>Acanthurus triostegus</i> (Linnaeus, 1758)	0		2	4.9-5.2
<i>Zebrasoma desjardini</i> (Bennett, 1836)	1	5	0	
Apogonidae				
Apogonidae	1	4.8	0	
Belontiidae				
<i>Tylosurus crocodilus</i> (Péron and Lesueur, 1821)	7	15-30	0	
Diodontidae				
<i>Diodon liturosus</i> (Shaw, 1804)	1	27	0	
Ephippidae				
<i>Platax teira</i> (Forsskål, 1775)	2	8.9-11.8	11	4-13
Fistulariidae				
<i>Fistularia commersonii</i> (Rüppell, 1838)	2	42-52	0	
<i>Fistularia petimba</i> (Lacepède, 1803)	4	18-39	2	14-16
Gerreidae				
<i>Gerres oyena</i> (Forsskål, 1775)	0		2	
Haemulidae				
<i>Plectorhinchus schotaf</i> (Forsskål, 1775)	2	11.8-13.5	0	

Labridae

<i>Cheilinus oxycephalus</i> (Bleeker, 1853)	4	3.7-5	0	
<i>Cheilio inermis</i> (Forsskål, 1775)	1	13.3	1	10
<i>Thalassoma hardwicke</i> (Bennett, 1830)	0		1	7

Lethrinidae

<i>Lethrinus harak</i> (Forsskål, 1775)	13	4.9-13	6	5-15.5
<i>Lethrinus lentjan</i> (Lacepède, 1802)	5	5.4-7.9	2	5-9
<i>Lethrinus mahsena</i> (Forsskål, 1775)	1	8	2	7-8.9
<i>Lethrinus nebulosus</i> (Forsskål, 1775)	1	10	2	7-7.1

Lutjanidae

Lutjanidae	0		2	5.5-8.4
<i>Lutjanus fulviflamma</i> (Forsskål, 1775)	26	5.2-10.6	60	4-11.5

Monacanthidae

<i>Amanses scopas</i> (Cuvier, 1829)	1	5.3	3	3-4
Monacanthidae	1	4	1	5.9

Mugilidae

<i>Crenimugil seheli</i> (Forsskål, 1775)	2	10.1-11.1	0	
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Mullidae

<i>Mulloidichthys vanicolensis</i> (Valenciennes, 1831)	9	6-12	1	5
<i>Parupeneus macronemus</i> (Lacepède, 1801)	1	9	0	

Ostraciidae

<i>Lactoria cornuta</i> (Linnaeus, 1758)	2	8.9-9.5	1	5
<i>Lactoria diaphana</i> (Bloch and Schneider, 18 01)	0		9	2-6.5
<i>Lactoria fornasini</i> (Bianconi, 1846)	0		2	4.5-6.3
Ostracid sp	0		1	1.2

Plotosidae				
<i>Plotosus lineatus</i> (Thunberg, 1787)	0		5	
Pomacentridae				
<i>Abudefduf septemfasciatus</i> (Cuvier, 1830)	0		4	6-6.5
<i>Abudefduf sexfasciatus</i> (Lacepède, 1801)	0		2	6-7
<i>Abudefduf vaigiensis</i> (Quoy and Gaimard, 1825)	3	5-5.7	1	5
<i>Dascyllus trimaculatus</i> (Rüppell, 1829)	2	2-3.8	0	
Pomacentridae	3	9.2-10	0	
Pomacentrus	0		1	5
Scaridae				
<i>Leptoscarus vaigiensis</i> (Quoy and Gaimard, 1824)	7	7-11	8	5-9.5
Scorpaenidae				
<i>Scorpaenopsis oxycephala</i> (Bleeker, 1849)	0		5	4.2-6.2
<i>Scorpaenopsis venosa</i> (Cuvier, 1829)	0		1	5
Siganidae				
<i>Siganus luridus</i> (Rüppell, 1829)	0		1	4
<i>Siganus sutor</i> (Valenciennes, 1835)	38	3.4-12.2	30	4.1-10.6
Soleidae				
<i>Pardachirus marmoratus</i> (Lacepède, 1802)	0		1	5.6
Sphyraenidae				
<i>Sphyraena jello</i> (Cuvier, 1829)	1	13.5	0	
Syngnathidae				
<i>Syngnathus acus</i> (Linnaeus, 1758)	0		3	11.8-13.5

Tetraodontidae				
<i>Canthigaster valentini</i> (Bleeker, 1853)	1	6	1	4
<i>Tetraodon lineatus</i> (Linnaeus, 1758)	0		1	8
Tetrarogidae				
<i>Ablabys macracanthus</i> (Bleeker, 1852)	0		1	4.2

The sizes ranged between 5.2 - 10.6 cm (NEM) and 4 - 11.5 cm (SEM) for Lutjanidae; and 3.4 - 12.2 cm (NEM) and 4.0 -10.6 (SEM) for Siganidae. Other dominant families were Lethrinidae, Mullidae and Pomacentridae of size range 4.9-15.5 cm, 6-12 cm and 2.0-10.0 cm respectively. Abundance showed no significant variation between the two sites. The mean abundance was 34.5 at Blue Lagoon and 53.37 at Watamu Beach. In some cases a diverse representation of species belonging to one family was observed. For example, fish belonging families Pomacentridae were represented by about 6 species (*Abudefduf septemfasciatus*, *Abudefduf sexfasciatus*, *Abudefduf vaigiensis*, *Dascyllus trimaculatus* Pomacentrid sp, *Pomacentrus*). Their sizes ranged between 2-10 cm. Ostraciidae was represented by 4 species whose size range was 1.2-9.5 cm (*Lactoria cornuta*, *Lactoria diaphana*, *Lactoria fornasini*, Ostracid sp) and Lethrinidae had 4 species of size range 4.9-15.5 (*Lethrinus harak*, *Lethrinus lentjan*, *Lethrinus mahsena*, *Lethrinus nebulosus*).

Figure 13 shows the taxa of juveniles sampled from the two sites during SEM (A) and NEM (B). The dominant taxa were Lutjanids (*Lutjanus fulviflamma*), and Siganids (*Siganus sutor*) which are associated with reef areas. Similarly, fish known to be temporarily associated with seagrass habitats like Lethrinidae (*Lethrinus harak*), Mullidae (*Mulloidichthys vanicolensis*), and Fistularidae (*Fistularia petimba*) were also sampled. Mullidae was most abundant in the Blue Lagoon during SEM, while Lutjanidae were most abundant in Watamu Beach during both seasons. Table 3 also shows that Lutjanidae was more abundant in Watamu Beach (60) than in the Blue Lagoon (26). Siganidae on the other hand was more abundant in Blue Lagoon (38) than in Watamu Beach (30).

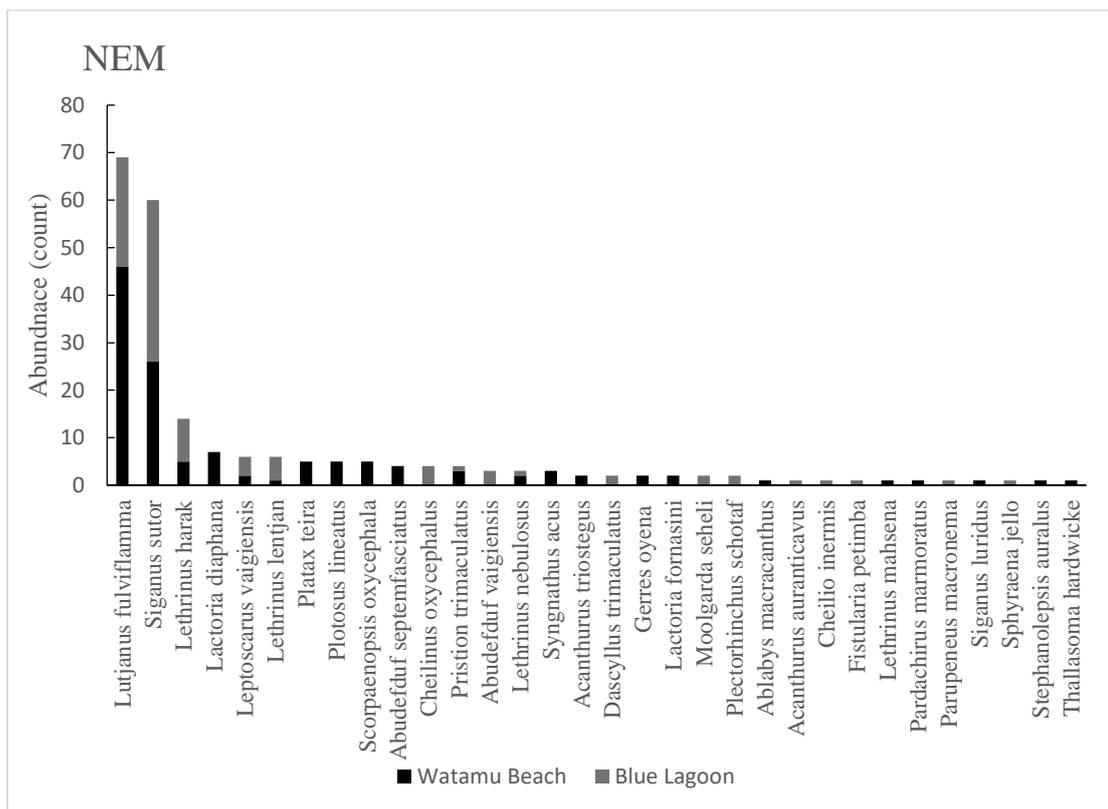
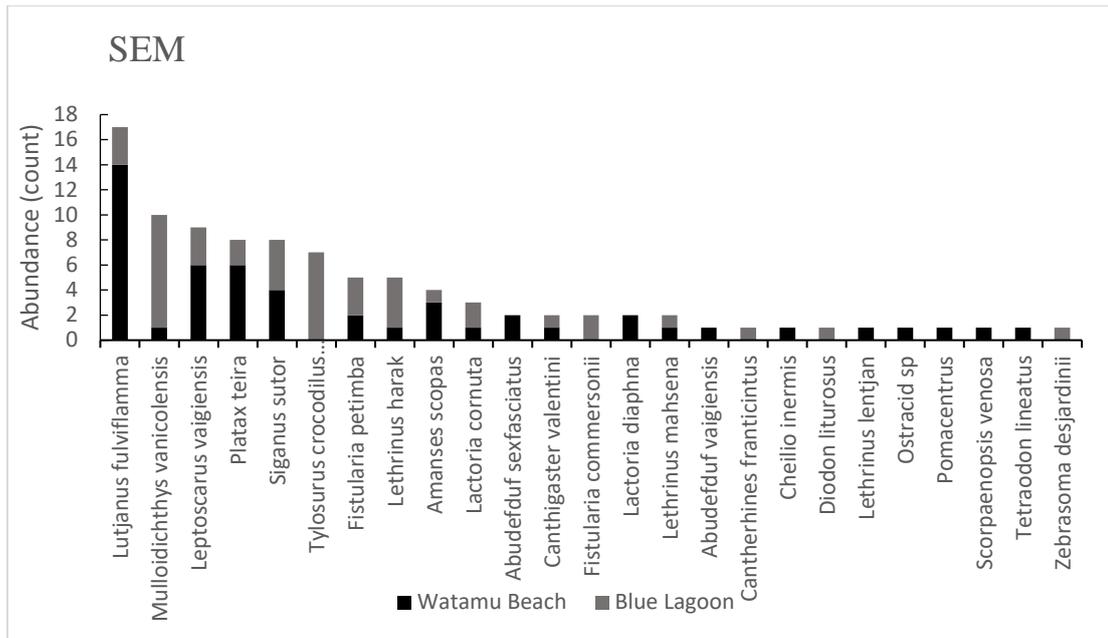


Figure 13: Juvenile fish collected from Watamu Beach (black bars) and Blue Lagoon (grey bars), during SEM (A) and NEM (B).

4.5.2: Juvenile fish species diversity

Overall species diversity (H') during the study period was higher in Watamu Beach ($H' = 3.03$) than in Blue Lagoon ($H' = 2.83$) ($p > 0.05$). Similarly, species richness was higher in Watamu Beach ($d = 5.5$) compared to Blue Lagoon ($d = 4.6$), although the difference was not significant (Figure 14). However, evenness, J was lower in Watamu Beach ($J = 0.94$) than in Blue Lagoon ($J = 0.95$, $p > 0.05$, Figure 14 A). Diversity (H') did not vary significantly between the two sites ($p < 0.05$), but ranged between 0 and 1.91.

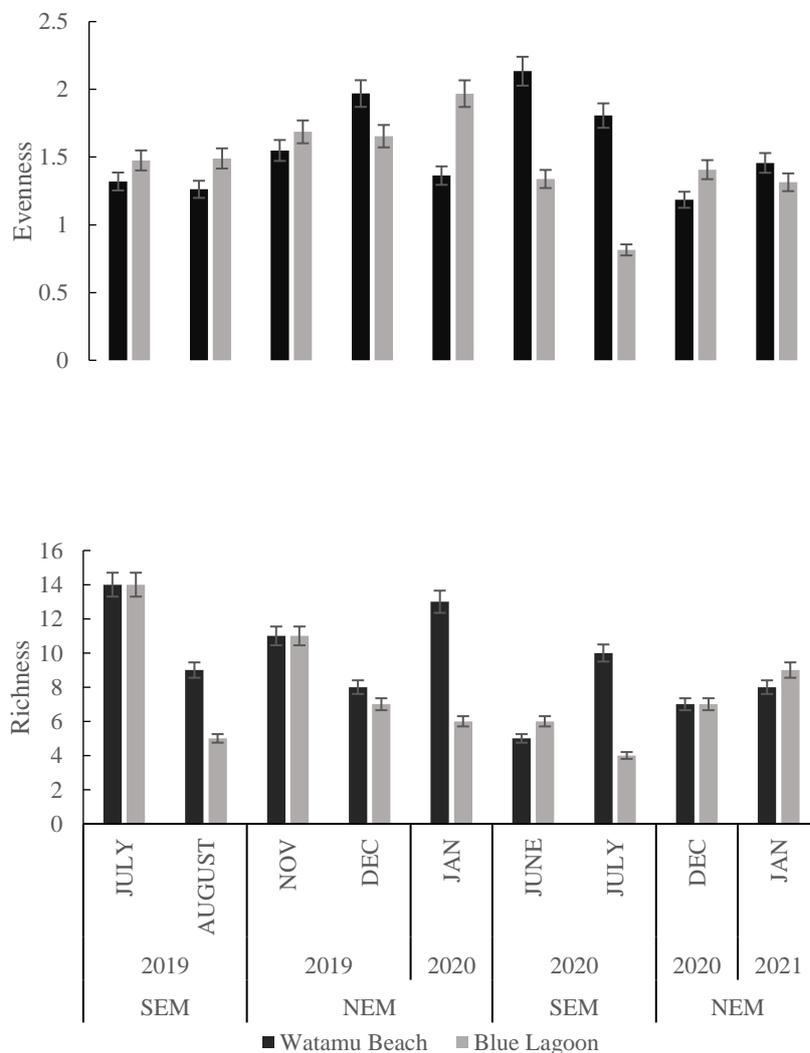


Figure 14: Mean monthly variation in juvenile (A) Evenness and (B) Richness for Watamu Beach (black bars) and the Blue Lagoon (grey bars), for seasons SEM and NEM.

4.5.3: Size range distribution of dominant juvenile species

Figure 15 shows the size ranges of the dominant juvenile fish species. The modal lengths of *Lutjanus fulviflamma* was 5 cm for site 1 and 7 cm at site 2. The dominant size for *Siganus sutor* was 5 at site 1 and 4 cm at site 2.

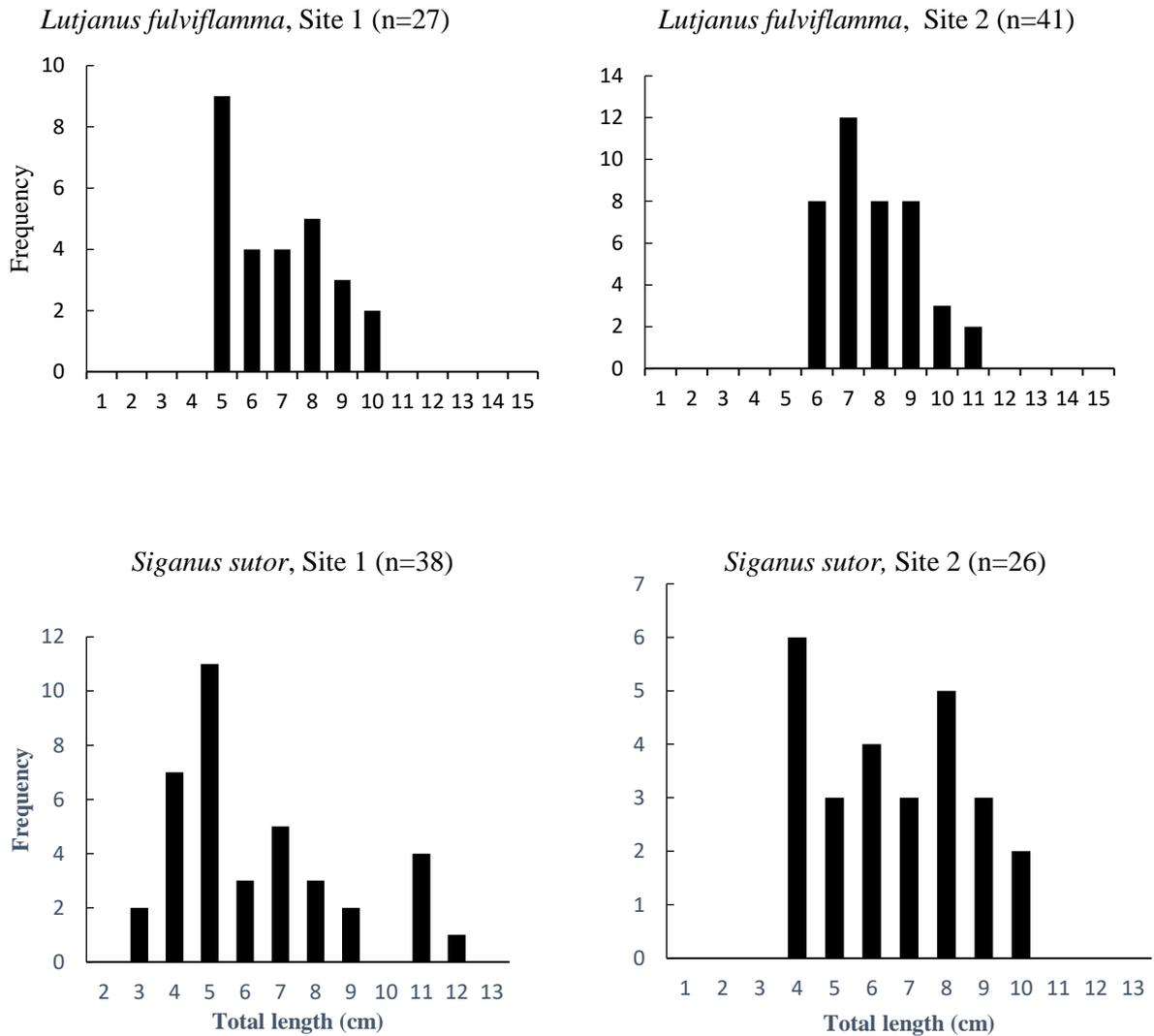


Figure 15: Length frequencies in centimeters of *Lutjanus fulviflamma* and *Siganus sutor* in site1, Blue Lagoon and Site 2, Watamu Beach.

4.6: Effect of seasonal variation on fish juvenile abundance

Fish juvenile abundance varied significantly between months and between seasons as shown in Figure 16. The highest abundance of juveniles was recorded in July 2019 in both Watamu Beach (70) and Blue Lagoon (42) sites. Peaks were observed in the year 1 and 2 NEM season indicating inter annual variability.

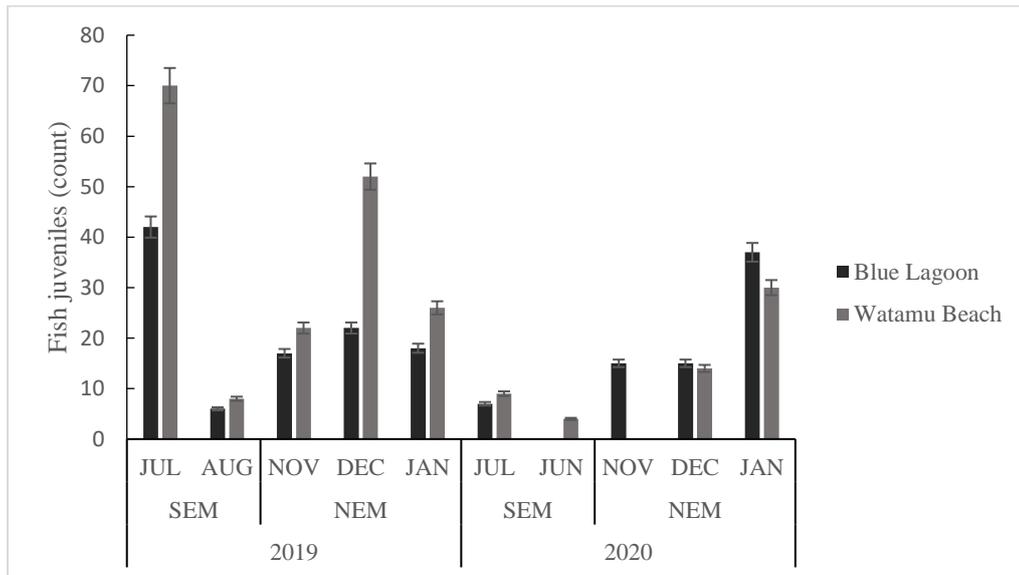
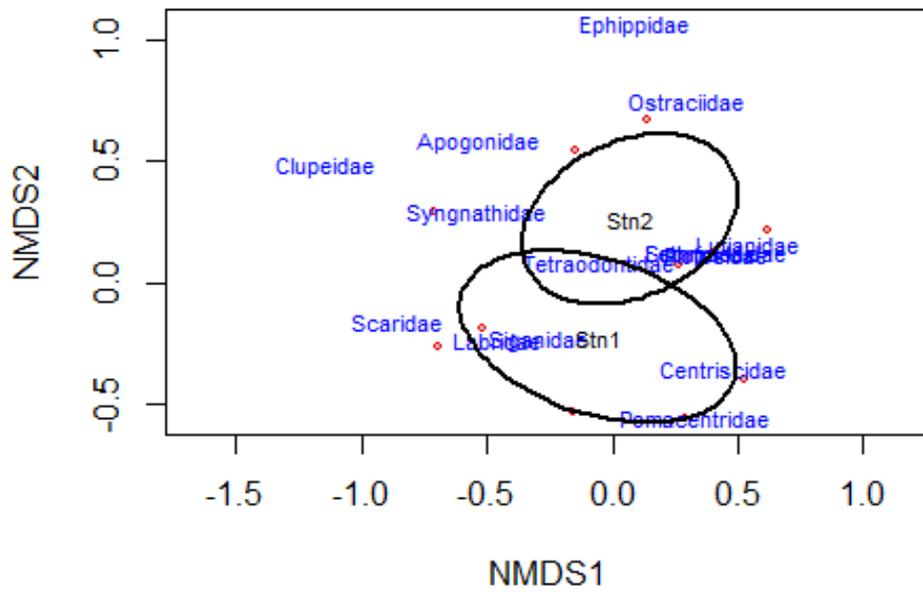


Figure 146: Monthly and seasonal variation in fish juvenile abundance in Watamu Beach and Blue Lagoon during the study period.

Figure 17 presents results of nonmetric dimensional scaling (nMDS) ordination that gives an overview of habitat preference for the juvenile families for season NEM (A) and SEM (B). During the NEM season (Figure 17A), Siganidae, Labridae and Pomacentridae were closely associate with the Blue Lagoon while Apogonidae and Lutjanidae were associated with the Watamu Beach. Tetraodontidae associated with both sites. Apogonidae, Clupeidae and Syngnathidae appeared outside the polygons but are associated with both sites while Scaridae was associated with the Blue Lagoon.

During season SEM (B), most juvenile families were found within the Blue Lagoon, although a slight overlap was observed for Lutjanidae, Monacanthidae, Scorpaenidae, and Labridae which appeared to correlate with both sites. Siganidae, Fistularidae, Lethrinidae were correlating with the Blue Lagoon. Clupeidae appeared farthest from the origin.

(A) Stress = 0.092



(B) Stress = 0.053

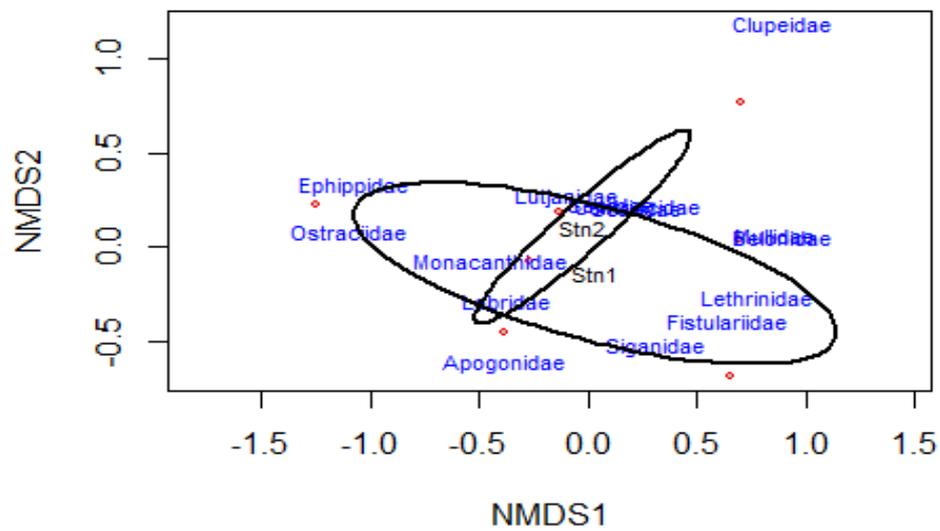


Figure 17: A chart showing the dominant juveniles sampled during NEM (A) and SEM (B) southeast monsoon season.

4.7: Effect of hydrographic parameters on juvenile abundance

Table 4 shows the correlation coefficients for hydrographic parameters against mean juvenile abundance. Temperature and Chlorophyll-*a* had a positive correlation with juvenile abundance, while seagrass cover and salinity negatively correlated to mean juvenile abundance. Correlation with salinity (negative) and Chlorophyll-*a* (positive) was statistically significant.

Table 4: Correlation coefficients between hydrographic properties and juvenile abundance

	Correlation Coefficient	p-Value
Temperature	0.05	$p > 0.05$
Salinity	-1.703	$*p < 0.005$
Chlorophyll- <i>a</i>	1.417	$*p < 0.005$
Seagrass cover	-0.001925	$p > 0.05$

*p denotes significant difference

CHAPTER FIVE: DISCUSSION

5.1: Fish larvae taxonomic composition and diversity

In total fish belonging to 35 families and 38 genera were collected from the two sites (Table 1). The dominant larvae (by numbers) belonged to families Blenniidae, Scaridae, Gobiidae and Labridae. These families have been reported in other studies to spend most of their life in seagrass beds (Tano *et al.*, 2017; Kopp *et al.*, 2010; Lugendo, 2007). Moreover, this finding was consistent with observations made by Mwaluma *et al.*, (2010) whose study reported a dominance of larvae belonging to families Labridae, Engraulididae and Gobiidae. The study was conducted at Watamu Marine Park, a site that neighbors one of Site 1 (Blue Lagoon) in the present study. The proportions of fish dominance showed that only five families dominated the catch, while the rest composed of rare fish larvae families. This observation is similar to findings reported by Chande *et al.* (2019); Kaunda-Arara *et al.* (2006); Hicks and McClanahan (2012); and Kindong *et al.* (2020). Shannon-Weiner diversity did not show a significant variation between sites. The range (H' 0.8-1.91) suggests that diversity of the larvae families is moderate, this implies that dominating larvae correlate to other families present at both sites. This observation is consistent with the nMDS charts, that display an overlap in families sampled within the sites of study (Figure 12).

All the three larval stages were present from samples of larvae belonging to families Gobiidae and Blenniidae. The presence of all three larval stages is an indication of self-recruitment, the sampled recruits are offspring of parents in the same population. This phenomenon has been described for Gobiidae and Blennidae (Mwaluma *et al.*, 2011, Green *et al.*, 2015). Three larval stages of families belonging to Callionymidae and Syngnathidae were also present, however, these families have not been described as selfrecruiting, suggesting that these larvae were retained in the seagrass beds after dispersal of larvae (Patrick *et al.*, 2021). For some fish families, only one stage of the larvae was sampled in the present study. For instance, larvae of fish belonging to families Myctophidae, Istiophoridae, Nemipteridae, Serranidae, Nomeidae, Lethrinidae, Leiognathidae were encountered at preflexion stage.

It is probable that these fish migrate to other habitats at different life stages, due to ontogenetic migration (Green *et al.*, 2015). However, this stochastic appearance cannot be conclusively attributed to ontogenetic migration because the sampling was conducted at specific months of the monsoon season. In the month of November (NEM season), preflexion larvae were not encountered but were collected in the next month. The numbers started increasing as NEM season progressed while postflexion larvae decreased in number (Figure 9). According to Okemwa (2019), increasing sea temperatures during NEM season can trigger spawning events because of the high productivity, hence the higher relative abundance of preflexion larvae than postflexion larvae.

5.2: Seasonal distribution of fish larvae

The larval supply in Watamu was influenced by seasonality with higher abundances recorded in NEM than in SEM season. This observation is similar to findings reported in studies by Kaunda *et al.*, (2009) and Mwaluma *et al.* (2010, 2011, 2014, 2021). The studies show that calmer NEM provides optimal conditions for food production (warm temperature) and enhance survival of the larvae (mild currents). The SEM along the Kenyan coast is associated with strong winds and currents due to the reversal of the East Africa Coastal Current. These conditions are not favorable for reproduction in fish (Mc Clanahan 1988; Kauda-Arara *et al.*, 2009; Mwaluma *et al.*, 2011). Additionally, the seasonal variability in abundance between year 1 NEM season and year 2 NEM season, could be attributed to variation in fish spawning regimes and abiotic factors that control distribution and abundance of larvae (Mwaluma *et al.*, 2010). The diversity, evenness and species richness were higher in NEM season than in SEM season, which is consistent to observation made by Mwaluma *et al.*, (2010). Ostraciidae was the only family that was not sampled during NEM season, but was present in SEM season both as preflexion and postflexion larvae. Other larvae belonging to families Acanthuridae, Atherinidae, Callionymidae, Diodontidae, Exocoetidae, Istiophoridae, Pomacentridae, Leiognathidae, Lethrinidae, Lutjanidae, Myctophidae, and Sphyraenidae, were sampled in NEM season, but were not encountered in SEM season. As discussed by Okemwa *et al.*,

(2019) the warm temperatures experienced during NEM can trigger spawning events and increased settlement of larvae due to increased food supply, hence the higher number of larval families sampled in NEM season. Reef fishes also form spawning aggregation between November and February in the NEM season (Øvrebø and Edgar, 2018). Among the larvae sampled belonged to families Acanthuridae, Labridae, Lethrinidae, Lutjanidae which are known to form spawning aggregations (Robinson *et al.*, 2008). This could also explain why more preflexion larvae were sampled during NEM season, the spawning season for most fishes.

Since recruitment depends mostly on offshore spawning, it is expected that preflexion larvae are supplied into shallow habitats during NEM season (Patrick *et al.*, 2021). The occurrence of different larval stages of development for larvae belonging to different families indicates a temporal variation in spawning, variation in settlement patterns, dispersal patterns and survival of larvae (Nzioka 1979, Mwaluma *et al.*, 2010).

An interannual variability of larval abundance was observed by Mwaluma *et al.*, (2011) and Kaunda-Arara *et al.*, (2006), with the latter study reporting peaks in abundance during NEM season, and further explained that rough SEM season facilitates transport of larvae offshore, as the calm NEM season favors settlement: temperatures and nutrients (Okemwa *et al.*, 2019). Although zooplankton abundance correlated positively with larval abundance, monthly variation shows a different pattern with higher zooplankton abundance in SEM season specifically in the month of August for year 1, and July for year 2 ($p > 0.05$).

5.3: Effect of hydrographic parameters on fish larvae abundance

Chlorophyll-*a* and zooplankton correlated positively with larval abundance while temperature was negatively correlating to larval abundance. Zooplankton abundance showed a significant influence on 13 families. Previous studies show that zooplankton abundance, temperature, Chlorophyll-*a* were found to positively influence larval distribution in studies along North Kenya Banks and in Malindi Marine Park. These observations concur with our findings, on

the contrary, temperature correlated negatively to larval abundance (Kaunda-Arara *et al.*, 2009; Mwaluma *et al.*, 2021).

5.4: Juvenile fish species composition and diversity

Juvenile fish belonging to 41 species and 28 families were sampled from the two sites. A higher abundance of juveniles was collected at the Blue Lagoon, but the difference was not statistically significant. However, evenness and diversity were higher in Watamu Beach than in the Blue Lagoon ($p > 0.05$). This observation is contrary to the assumption that species richness and diversity increase with increasing seagrass density (McCloskey and Unsworth, 2015; Whitfield, 2017;). Apparently, as was noted by Ambo-Rappe *et al.* (2013), there has not been consistent observation on the effect of seagrass cover on abundance of macrofauna in seagrass. For instance, Jelbart *et al.*, (2007) observed a higher abundance of fish in patched seagrass beds (Ambo-Rappe *et al.*, 2013), but McNeill and Fairweather (1993) made a contrary observation. The latter study reported a greater diversity of fish in patched seagrass beds than in continuous seagrass beds. It is also reported that high fish abundance and catches are reported in seagrass beds both in Tanzania and Kenya, irrespective of their coverage (Ochieng and Erfteimeijer, 2003). The edge effect which is linked to patchy seagrass beds also influences abundance of juvenile fish. The patches enable penetration of water and food to the spaces within the patches (Irlandi *et al.*, 1995). We could also deduce that these patches may be too small to sustain predatory fish thus patchiness enhances survival of fish hence the higher abundance of juveniles in the patched seagrass beds (Jelbart *et al.*, 2007). Therefore, this variation in observation may suggest that preference of bed size may be taxon specific and not necessarily a factor of seagrass cover (Bell *et al.*, 2001).

Since the variation in abundance between Blue Lagoon and Watamu Beach was not significant, it is postulated that when larvae are homogeneously distributed, and random recruitment into seagrass beds is allowed, no variation in the diversity will occur between seagrass beds of lower and higher cover (McNeill and Fairweather, 1993).

A high density of larvae is retained in the small beds for several months before migration, probably the reason for the observed higher fish abundance in patchy beds than in continuous beds (Jelbert *et al.*, 2007). Therefore, most of the individuals sampled in these beds may have been retained after dispersal and settlement of larvae, before their migration to the subadult habitats (Bell *et al.*, 1987; Jelbert *et al.*, 2007).

Dominant fish juveniles belonged to families Lutjanidae and Siganidae at both sites. These findings are similar to those reported by Ambo-Rappe *et al.*, (2013) at Ambon Bay, eastern Indonesia. The current results show a different juvenile fish composition from the one observed in intertidal shallow lagoons of Watamu Marine National Park, an adjacent site dominated by Gobiidae, Blenniidae, Pomacentridae and Labridae (Sindorf *et al.*, 2015). The difference may be due to the difference in habitat composition, the former being composed of seagrass the latter being a rocky intertidal site. However, a few families similar to those sampled by Sindorf *et al.*, (2015) were present at both sites in the present study, but in lower densities, possibly because they inhabit both areas at different times or at different development stages (Zhang *et al.*, 2022). Families of Scaridae and Labridae are typical seagrass dwellers (Lugendo *et al.*, 2007b, Kopp *et al.*, 2010); but along with Lutjanidae and Mullidae they inhabit the reef at adult stage (Dorenbosch *et al.*, 2006). The presence of these families in our samples suggests that the seagrass beds at Watamu function as nurseries for fish that inhabit the neighboring reefs (Alonso *et al.*, 2014). These families are transient species, habitat preference is influenced by their feeding behavior, and so inhabit shallow areas during the juvenile stages before moving to offshore adult habitats (Green *et al.*, 2015). Similarly, while investigating differences in juvenile abundance associated with seagrass beds and the reef, Kimirei *et al.*, (2011) found a high abundance of reef associated species (*Lethrinus harak*, *Lethrinus lentjan*, *Siganus sutor* and *Lutjanus fulviflamma*) in seagrass beds of Mbegani. The same species were also sampled within the reef, but at adult stage (Kimirei *et al.*, 2013).

This is a clear indication of ontogenetic migration (fish migrating to other habitats at different life stages) while trying to meet their changing dietary and physiological requirements, spawning and competition (Sheaves, 2009).

Most of the self-recruiting juvenile fish are cryptic and benthic hence not easily collected in the seine net, among the ones mentioned are Blenniidae, Gobiidae and Syngnathidae (Brandl *et al.*, 2018). These cryptobenthic fishes are normally 10 cm long and below in length when adults, therefore can easily escape capture. This may explain why these three species were not collected as juveniles but were present as larvae (Kesici and Dalyan, 2018).

5.5: Seasonal distribution of juveniles

Juvenile abundance shows a seasonal variability, with SEM season recording higher values for abundance, evenness, richness and diversity. The higher abundance of juvenile fish observed during SEM than in NEM season is contrary to what most studies report, they report higher fish catch during the NEM season (McClanahan 1988; WVDEP, 2018; Gondal *et al.*, 2021). Sigana *et al.* (2002) assessed the fish composition along Kilifi Creek and found a higher abundance, diversity and richness during NEM season compared to SEM season. The observations of this study are however similar to Emania *et al.* (1996) who observed a peak abundance in June (SEM season) while surveying fishes associated with mangrove beds of Gazi. In this study, the peak abundance was observed in July, which is also in SEM season.

A higher abundance of juveniles in the seagrass beds during this season suggests that the beds are preferred habitats for juveniles during SEM season. These beds are in protected zones, the sheltered bays, therefore have reduced wave action, hence provide suitable refuge and shelter from the rough season (Gullström *et al.*, 2002; Hedberg *et al.*, 2019; Parsons *et al.*, 2014). These conditions are suitable for retention of larvae, recruits and juveniles (Parsons *et al.*, 2014).

Hydrographic parameters are influenced by seasons which subsequently influence juvenile abundance. Higher values of chlorophyll-*a* were reported during SEM season. This coincides

with the higher juvenile abundance also observed during SEM season. Higher chlorophyll-*a* simply forecasts an abundance in food supply for juveniles during this season (Parsons *et al.*, 2014). This observation is also supported by the significant positive correlation observed between juvenile abundance and chlorophyll-*a* content (Table 4).

Occurrence of fish during one season suggests that the fish settlement patterns differ seasonally. Recruits may have shifted to offshore habitats in the subsequent season (Okemwa *et al.*, 2019). Most of the species sampled in NEM season but missing in SEM season belonged to reef fish families associated with seagrass beds at specific stages of development. Sphyraenidae for instance, is said to depend on shallow habitats, seagrass and mangrove, as its nursery (Gajdzik *et al.*, 2014). Sepiidae and Monodactyllidae which were only sampled in SEM belong to reef species that inhabit mangroves and seagrasses temporarily, therefore suggesting an ontogenetic migration to the neighboring reefs during NEM (Igulu *et al.*, 2014; McDevitt-Irwin *et al.*, 2017). Temporary residence of these families justifies the hypothesis that the main function of these habitats are nurseries (Igulu *et al.*, 2014; McDevitt-Irwin *et al.*, 2017). Constant appearance of juveniles in various size ranges is proof of continuous fish spawning albeit recruitment prevails during NEM season (Kamau *et al.*, 2021).

The non-metric multidimensional scaling plots produced (Figure 12, 17), show an overlap in fish community associated with the two sites for both larvae and juveniles in both seasons. In larvae however, specific families associated with particular habitats during NEM season. The association to specific habitats during the NEM season may have been influenced by increased food supply following the warmer conditions of that season (Øvrebø and Edgar, 2018; Okemwa *et al.*, 2019). During SEM season most families sampled correlated with both sites suggesting that continuous and patchy seagrass can attract similar ichthyofauna assemblages. The overlap in fish communities may be an indication that the habitat conditions are more or less similar, hence can accommodate similar fish communities.

5.6: Effect of hydrographic parameters on juvenile fish abundance

Chlorophyll-*a* and temperature positively influenced juvenile abundance, while salinity was found to be inversely correlated to juvenile abundance (Table 4). These were found to vary monthly and seasonally. The higher juvenile abundance during SEM season coincided with higher values of Chlorophyll-*a* during SEM season, which is indicative of high nutrients in sea water, abundant food supply for juveniles during this season.

CONCLUSION AND RECOMMENDATIONS

Conclusions

The present study noted no significant difference in larval abundance between the two seagrass habitats of Watamu. Therefore, seagrass beds of varying seagrass cover, whether continuous or patchy, form a continuous seascape that supports recruitment functioning as nurseries. The most common fish larvae sampled belong to families Gobiidae, Scaridae and Blenniidae. Presence of the three larval stages of families Gobiidae and Blenniidae suggests self-recruitment by these families. The results of this study show that coral reef-associated fish species utilise seagrass beds as nursery grounds. Presence of larvae belonging to families such as Lutjanidae, Siganidae, Lethrinidae is indicative of transient nature of these families and the interconnectedness of the seagrass beds with the adjacent reef.

A significant difference was observed in abundance of larvae and juveniles between seasons, thus seasonality plays a significant role in fish larvae and juvenile recruitment. An abundant and diverse larval assemblage was observed in NEM than in SEM season. Seasonal variation in the stages of larvae development was influenced by hydrographic parameters, variation in settlement patterns and dispersal of larvae. Zooplankton abundance, salinity and Chlorophyll-*a* significantly correlated with fish juvenile abundance.

Recommendations

To better understand how these nursery beds are connected to other seascapes, further studies with the objective of examining the adult fish composition within the adjacent reefs is recommended. Considering that a better understanding the ecological role of these seagrass beds in relation to the health status of the seagrass is equally important; there is need for a study with the objective of examining how other seagrass variables (shoot density, canopy height) can influence nursery functions of seagrass beds as a habitat while correlating these variables to juvenile abundance.

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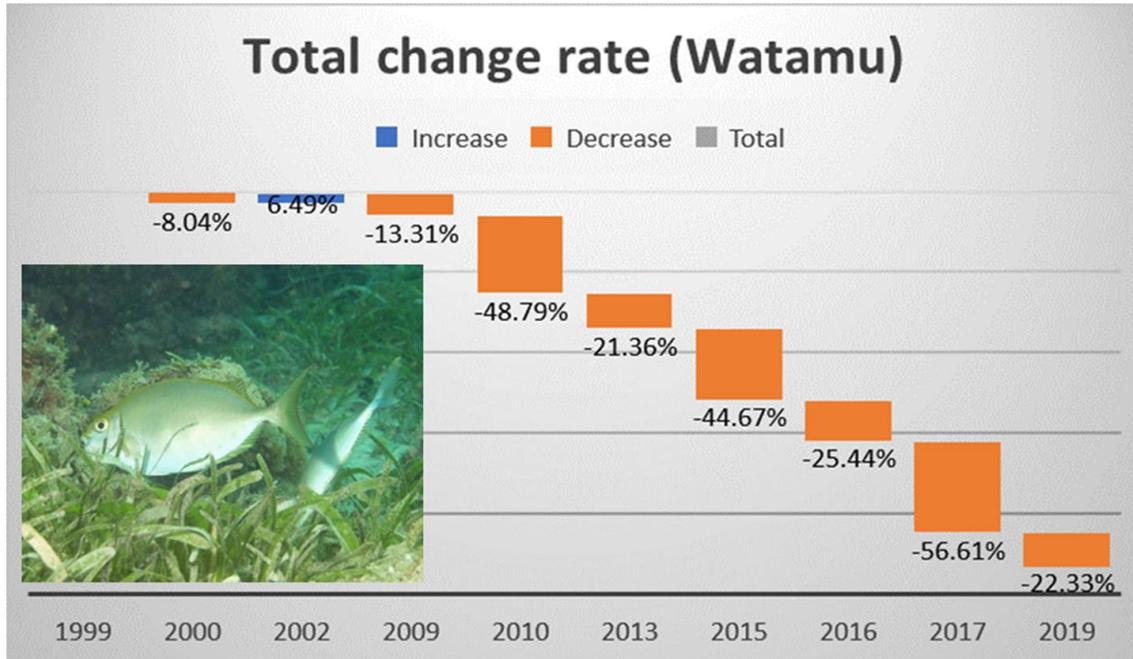
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APPENDICES

Appendix 1: Seagrass cover change, Watamu

Seagrass cover change from 1999-2019

A graphical presentation of seagrass cover change in Watamu between 1999 and 2019.

Source: Ngisiange 2022, unpublished data

Appendix 2: Definition Of Terms

Recruitment is the addition of newly settled individuals from the pelagic larval phase which contributes to replenishment of marine fish population. It is called a pelagic larval phase because the larvae develop to competency in the water column.

The **process of recruitment** refers to fish transitioning to a different life stage, that is, the development of fish from eggs through the pelagic larval phase, or from larvae to juvenile stage.

Ichthyoplankton is the early life stages (eggs and larvae) of marine fishes.

Larvae is the developmental stage between hatching (or birth) and attainment of full external meristic complements (fins and scales) and loss of temporary specialisations for pelagic life; yolk sac through postflexion stage inclusive.

Juvenile stage is morphologically similar to the adult. It is a developmental stage from attainment of full external meristic complements and loss of temporary specialisations for pelagic life to sexual maturity.

Ontogenetic migration: an ecological phenomenon where different life stages migrate into different habitats, or part of habitat. An organism, in this case fish, changes its habitat during its ontogeny.

Ontogeny: the development process of a living organism, in this instance, fish.

Species richness is the number of species in the community.

Species evenness is a measure of how close species are in a community. It is a measure of similarity that considers the relative species abundance. Species abundance is the number of individuals per species.

Shannon Diversity index is the rarity or commonness of species within a community. It considers the evenness and abundance of species present in a particular community.

Appendix 3: Sample images of larvae and juveniles that were sampled from the study sites

A. Fish Larvae

1.		Blennidae, <i>Petrocirstes mitratus</i> 11mm
2.		<i>Gobiidae</i> , 8.5 mm
3.		<i>Apogonidae</i> , 15mm
4.		<i>Leiognathidae</i> , 16mm

5.		<i>Apogonidae</i> , 3.12mm
6.		<i>Leiognathidae</i> , 13mm
7.		Ostracion
8.		<i>Labridae</i> , 8mm, 9mm, 11mm
9.		<i>Syngnathidae</i> , 7.2 mm

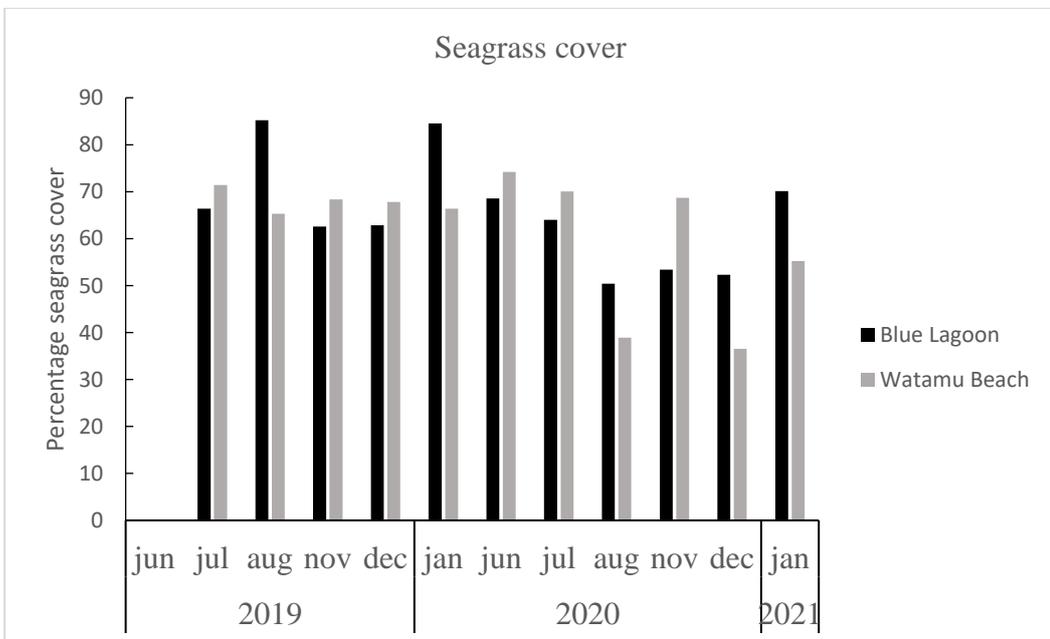
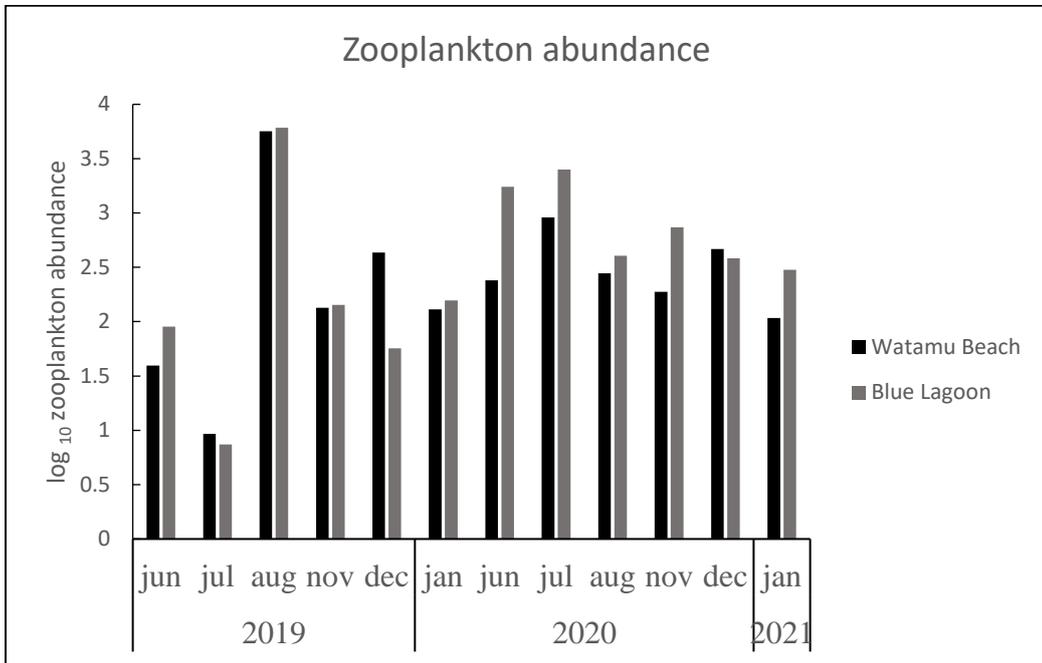
10.		<i>Scaridae</i> , 14 mm
11.		<i>Gobiidae</i> , 9mm
12.		<i>Labridae</i> , 14mm
13.		<i>Scaridae</i> ,

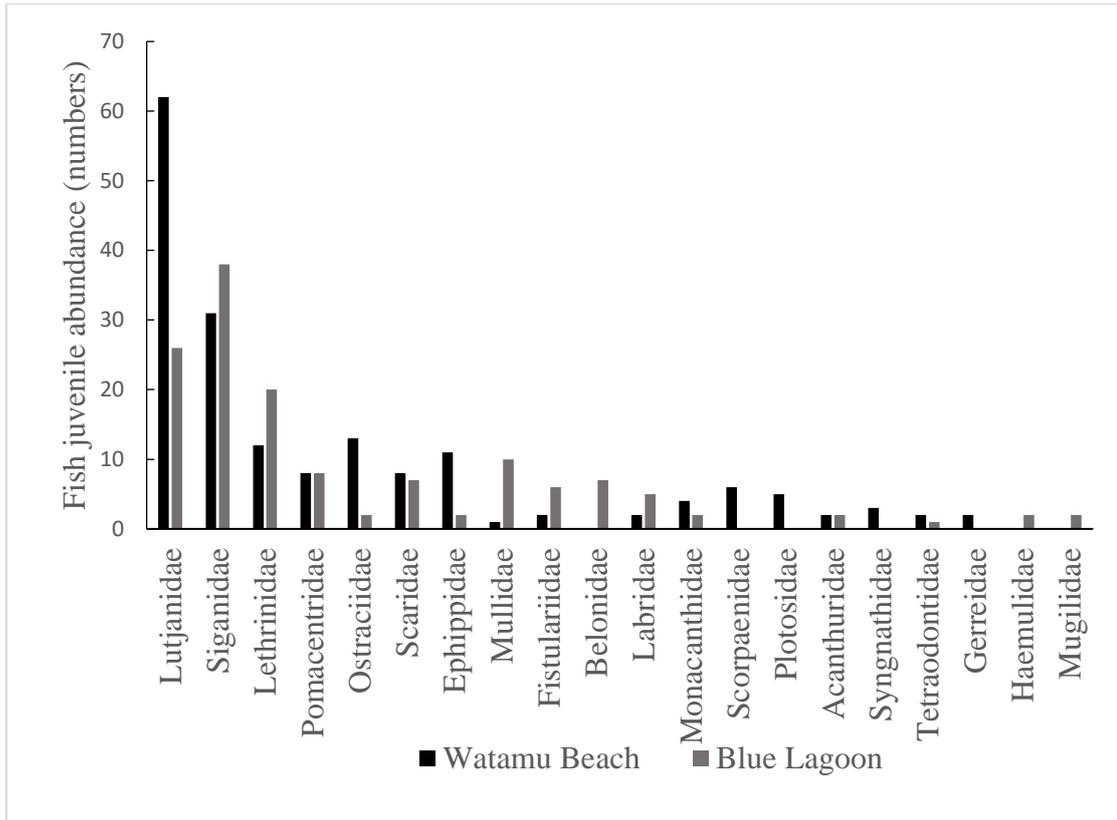
B. Fish juveniles sampled from the two study sites

1.		Clupeidae
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2.		Lutjanidae
3.		Diodontidae
4.		Scaridae <i>L. vaigiensis</i>
5.		Labridae <i>Cheilio inermis</i>
6.		Monacanthidae

Appendix 4: Results for zooplankton abundance and seagrass cover





Appendix 5: Results from ANOVA statistics**A. Water Quality Variables**

Parameter	Factor	ss	df	MS	F	P
Chlorophyll-a						
	Season	0.000	1	0.000	0.008	0.928
	Year	13.047	1	13.047	347.770	2.81e-12
	Site	0.086	1	0.086	2.302	0.149
	Month	4.845	4	1.211	32.287	1.77e-07
Temperature						
	Season	26.111	1	26.111	46.044	4.38e-06
	Year	4.636	1	4.636	8.176	0.0114
	Site	0.057	1	0.057	0.100	0.7559
	Month	6.887	4	1.722	3.036	0.0486
Salinity						
	Season	0.0971	1	0.09711	2.989	0.1031
	Year	0.124	1	0.12400	3.817	0.0685
	Site	0.01	1	.01000	0.308	0.5866
	Month	0.144	4	0.03603	1.109	0.3864

B. Community Analysis, Larvae

Parameter	Factor	ss	df	MS	F-value	P
Abundance of larvae						
	Sites	1	1	1.0	0.005	0.94229
	Season	762	1	762.1	4.098	0.04496
	Month	676	4	169.0	0.909	0.00386
	Year	1609	1	1609.2	8.653	0.46085
Shannon-Wiener diversity index (H')						
	Sites	0.638	1	0.6380	1.499	0.227
	Season	0.017	1	0.0173	0.041	0.841
	Month	0.099	1	0.0988	0.232	0.632
	Year	0.141	1	0.1413	0.332	0.567
Margalef's species richness index, (D)						
	Sites	6.02	1	6.021	1.128	0.294
	Season	0.00	1	0.00	0.00	0.995
	Month	3.39	1	3.386	0.634	0.430
	Year	5.09	1	5.091	0.954	0.334

 Pielous's index (J') of

evenness

Sites	6.02	1	6.021	1.128	0.294
Season	0.00	1	0.00	0.00	0.995
Month	3.39	1	3.386	0.634	0.430
Year	5.09	1	5.091	0.954	0.334
Sites	6.02	1	6.021	1.128	0.294

C. Community analysis, Juveniles

Abundance

Sites	0.51	1	0.5115	1.0	0.319
Season	0.02	1	0.0189	0.037	0.848
Month	2.31	4	0.5787	1.131	0.344
Year	0.00	1	0.00	0.00	0.994

Shannon-Wiener diversity

 index (H')

Sites	1.799	1	0.0136	0.038	0.8472
Season	6.294	1	1.7988	5.055	0.0390
Month	2.780	4	1.5735	4.422	0.0135
Year	5.694	1	2.7798	7.812	0.0130

 Margalef's species

richness index, (D)

Sites	13.5	1	13.50	1.337	0.26446
Season	37.5	1	37.50	3.715	0.07187
Month	224.8	4	56.21	5.569	0.00527
Year	96.0	1	96.0	9.511	0.00711

 Pielous's index (J') of

evenness

Sites	13.5	1	13.50	1.337	0.26446
Season	37.5	1	37.50	3.715	0.07187
Month	224.8	4	56.21	5.569	0.00527
Year	96.0	1	96.0	9.511	0.00711
