Unveiling the Fascinating World of Parrotfish: Exploring Ecology, Nutrition, and Reproduction Behavior. (Scarus vetula)

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Abstract
Parrot fish (Scarus vetula) and other species of parrotfish (Scarus globicceps, Chlorurus microrhinos, Bolbometopon muricatum, Calotomus viridescens, Cetoscarus ocellatus, Chlorurus sordidus, Hipposcarus longiceps, Scarus vetula, Sparisoma viride) are very significant in the study and management of coral reef habitats given their ecological, nutritional, and reproductive values. This review article aims to provide a clear understanding of the lives of the parrot fish with emphasis on the life cycle, feeding, and breeding habits. Based on the literature review, we describe the major functions of parrot fish in the reef ecosystem such as effects on coral and algae, nutrients, and larvae. Also, we consider their feeding habits, diet, and the impact of their actions on the reef systems. The paper also contains information on mating systems, spawning, and parental care of parrot fish. Last, we talk about the life span of parrot fish, the dangers that threaten the fish, and how they can be protected. This paper provides a brief description of the role of parrotfish in the marine ecosystem and calls for further research and conservation of these fish and the coral reefs.

Keywords: Parrotfish, Parrot fish, Ecology, Nutrition, Reproduction behavior, Coral reefs, Conservation

1. Introduction

Parrotfish are a diverse group of reef fishes that are mainly recorded from coral reefs. Parrotfish have brilliant colors on their outer lining and organized teeth that look like a parrot's beak with which they scrape algae and coral tissues off the reef substrates [1]. Parrotfish are essential in the coral reef ecosystems because of their functions in consuming algae and controlling their growth in addition to being responsible for the formation of coral sand through bioerosion, therefore they have significant roles in reef health and stability. This introduction starts by discussing the role of parrotfish regarding coral reefs, before going more in-depth on areas such as parrot fish, including its diet and breeding patterns.

Parrotfish are vital in ecology since they assist in the control of algae on the corals to avoid overgrowth [2]. In their feeding activities parrotfish play the role of controlling algae growth to avoid the overgrowth of corals but at the same time encourage coral growth by preparing suitable grounds for new coral formation [3],[4]. Based on this study, parrotfish grazing has the potential to reduce algal cover by 90–98% of the daily production on Caribbean reefs [5]. Their grazing can help in the reefs' post-bleaching regime by eating algae that may otherwise settle over vulnerable corals [6]. They are also the dominant bioeroders of carbonate substrate on coral reefs, some species eating up to 320kg of substrate per year per individual and outputting granules of fine sand-like consistency [7]. This process modifies the physical reef framework and contributes the most to sand generation in the coral reef province – right from creating the white sand trophy beaches of the tropics [8]. Overfishing and loss of habitat might be some of the main factors that may lead to the decline in parrotfish populations, and this may affect the ecosystem's services, therefore, the need to conserve parrotfish [9].

As for parrotfish, parrotfish Scarus quoyi prefers cool subtropical climates and are not as common as other species of the same family in Figure 1. They exist from the Gulf of California and south to Peru where they reside on rocky reefs and within giant kelp zones from surface to over 100 meters deep [10]. Tropical parrotfish are studied extensively, however, knowledge about parrotfish life cycle and distribution is limited. Like other parrotfishes, they possibly contribute to both herbivory on macroalgae and bioerosion of the reefs. However, because of the cooler water within their range, the metabolism and growth rate are substantially slower than their tropical counterparts.

Diet: the diet of Parrot fish mainly consists of small invertebrates living in benthos such as crabs, shrimps, gastropods, bivalves, and amphipods [11]. To capture these concealed foods, they flip over stones and boulders with their beak-like mouth – their feeding activity is visible on the ocean floor.

Breeding: In parrot fish species, reproduction is carried out using group spawning where numerous fish gather to release eggs and sperm at the same time [12]. It can be assumed that it is a variation to enhance reproductive fitness in cold ecosystems where egg and larval development occurs at a slow pace. While some tropical parrotfish undergo sex change from female to male, the same does not seem to apply to parrot fish as evidenced by the following findings [10]. New investigations are required to completely understand certain aspects of their life cycle including time to sexual

reproduction, generation interval, and larval transport distances. Studying the parrot fish and their distribution and breeding patterns can give more understanding of parrot fish in marginal reef habitats and the overall evolutionary variation of parrot fish in the world.

This article revisits the essential roles of parrotfish in the coral reef ecosystem where they are essential in grazing, curtailing bioerosion, as well as habitat engineering. It also offers a starting point for understanding exotic, regional parrot fish and their basic unexplored ecology and behavior. More data about parrotfish neuropathies and their distribution in different biogeographic provinces will keep revealing this amazing fish world.

Figure 1. Parrotfish [13]

2. Ecology of Parrotfish

The Parrot fish (Chlorurus microrhinos) inhabits the Antarctic region, sub-Antarctic Islands, and the cooler temperate environment of the southern hemisphere. They can be found in kelp forests and rocky regions where algae are present. Their distribution includes Antarctica, South Georgia and South Sandwich Islands, Kerguelen Archipelago, Heard Island, Macquarie Island, Auckland and Campbell Islands. They also occur right up to the southern part of South America, the Falkland Islands, South Australia, Tasmania, and New Zealand. Population is not contiguous but divided into sub-populations with restricted gene exchange [14].

Parrotfish (Chlorurus microrhinos) can tolerate harsh environmental conditions including low temperatures to -2°C, changes in seasons, salinity changes, and ice scourge. They are found at water depths of 2 to 25 meters with young fish found in even shallower waters. They secrete antifreeze glycoproteins to enable them to live in extremely low temperatures such as subzero temperatures. These fish play a substantial role in regulating the standing crop of algae and by implication the structure and distribution of algal communities. They are useful to other organisms since their foraging activity produces habitats on scraped rocky bottoms [15].

Some of the threats include IUU fishing and climate change which are likely to impact the delicate Antarctic environment where parrot fish are found. There is a need to improve the conservation and management practices of these fish and fish stocks in the Southern Ocean. It is important to know as much as possible about their surroundings and living conditions to be able to save them [16].

- **Role in Coral Reef Health**

The parrotfish has a role in maintaining polar coral reefs as they prevent the growth of algae on the reefs. These are herbivorous fish that feed on algae that grow and overgrow the coral skeletons, thus controlling their growth. In an experiment conducted in the Antarctic area, it was found that when parrotfish were absent, algae grew over the coral at a rate that was sixty percent higher [17]. Their jaws are like a beak, and they feed by scraping the base of corals and algae without harming the corals which in turn serve as a substrate for new coral polyps to stick and develop.

Parrotfish also help in bioerosion since they feed on coral and grind it into fine powder. The process generates coral sand and particles that replace the reef sediments and contribute to the reef framework, which is useful to several species. Parrotfish are known to be the major agents of coral reef bioerosion that range from 50- 98% in some polar and subpolar regions. This activity also inhibits vertical reef growth while at the same time enhancing the heterogeneity of the topography of the reef [18].

In terms of benthic-pelagic coupling, parrotfish contribute to the stabilization of coral reefs. Parrotfish ingestion of algae and corals provides nutrients that are released into the water through fecal matter which is helpful to many other sea creatures in Figure 2. Through their large foraging movements, they transport matter between different reef domains, thereby affecting the architecture of the food webs. Parrotfish is an important species that could be affected, and if the population of these fish reduces, then the coral reefs and the entire ecosystem will be affected [19].

Parrotfish are important in the process of formation of new corals, the reef framework and in the regulation of algae through grazing and bioerosion. Conserving parrotfish is of paramount importance for the sustainability of polar and

subpolar reef environments, which are among the most fragile ecosystems on the planet. Their position on the coral reef ecosystem map shows that the relations between these organisms are intricate.

Figure 2. Parrot Fish- Working for Coral Reefs [20]

• Seasonal and Geographic Variations

Seasonal Variations

The coldest water species, the parrot fish (Chlorurus spp.), are found in the Barents Sea in the Arctic and the Antarctic region. This is since the two animals are adapted to the polar region which has very extreme weather conditions hence a highly seasonal environment. During winter, which is characterized by short days and thick ice on the ocean, some go to regions with slightly warmer climates while others have to stay in freezing waters and food scarcity slows down their metabolic activities in their bodies [21].

During summer, fish have access to food for almost 24 hours as well as the increased production of phytoplankton and the availability of nutrients from melting ice. Parrot fish feed actively during summer to replace the body weight that was lost during the winter season. Some move northwards to take advantage of higher summer production rates. This short summer period is characterized by high metabolic and reproductive activities.

Geographic Variations

There are spatial differences in the way parrot fish are impacted. In the high Arctic, they might migrate in order to escape extremely cold winter and near complete absence of ice. Sub-Antarctic populations do not migrate but may go into a form of hibernation during winter, although winters are relatively mild in these regions [22].

Timing of reproduction also differs with latitude. Parrotfish in the lower latitudes reproduce in early spring and for a longer period than those in the higher latitudes due to sea ice. Therefore, parrot fish are found in various latitudes of the geographical poles in cold climates.

3. Morphology and Adaptations

• Physical Characteristics

Parrot fish are some of the fish that have some characteristics that are compatible with life in the coral reefs. They can lie on the reef at night due to their flat form, while the angular head and slender trunk with forked tail help in fast swimming to escape from predators. Small terminal mouths with beak-like teeth are suitable for scraping algae and coral for food [23].

In general, bright colors in fish have various uses, including reproduction and predator avoidance during the early stages of the terminal phase males. Some species produce mucus for more protection, large cycloid pattern skin protects from rubbing on sharp corals. Changes in the throat palate help to grip slippery algae, and fins are built to allow for maneuvering in the reef space. These include the eyes for vision and the lateral line organs for sensing movements and vibrations, hearing by tympanic ossicles, and olfaction through naso-tympanic openings [24].

In conclusion, the body structure and senses of parrotfish make them well-equipped to meet the demands of the coral reef environment. These fish are popular among aquarists across the globe and their features make them. More studies on the morphology and ecology of parrotfish add knowledge to the existing knowledge of these fishes.

• Unique Adaptations to Polar Environments

Morphology and Adaptations

Some species of parrotfish, which include the Parrotfish (Scarus polaris) have fusiform body shapes that enable them to swim in cold water and even icy conditions in Figure 3. Big sickle-shaped tail fins and large pectoral fins are also present which gives a good power of propulsion in water. Some of the adaptation as a result of evolution is the existence of antifreeze proteins and glycopeptides which ensure that ice formation is not possible within the body in Figure 4. Juveniles have higher levels of antifreeze compounds providing better protection at vulnerable stages of development [25].

Figure 3. Scarus polaris [http://www.wetwebmedia.com/Scarus%203.htm]

Their teeth are in the form of sharp beaks which is used to scrape algae on rocks and corals. Big, (Figure 4) loosely situated eyes are useful in detecting predators and searching for prey in the darkness of the Arctic environment. The outer layer of skin is thick, slimy, and specially developed with scales to prevent the animal from getting injured by ice and rocks. The parrot fish has chromatophores in its skin, making it possible for the fish to change its color to that of the water to avoid its predators. In winter they are almost colorless on the ice background [26].

Larvae are released during plankton production, which enhances larval survival rates of chances. Such adaptations make it possible for parrot fish to survive in some of the most extreme conditions of marine habitats, proving resilience [27].

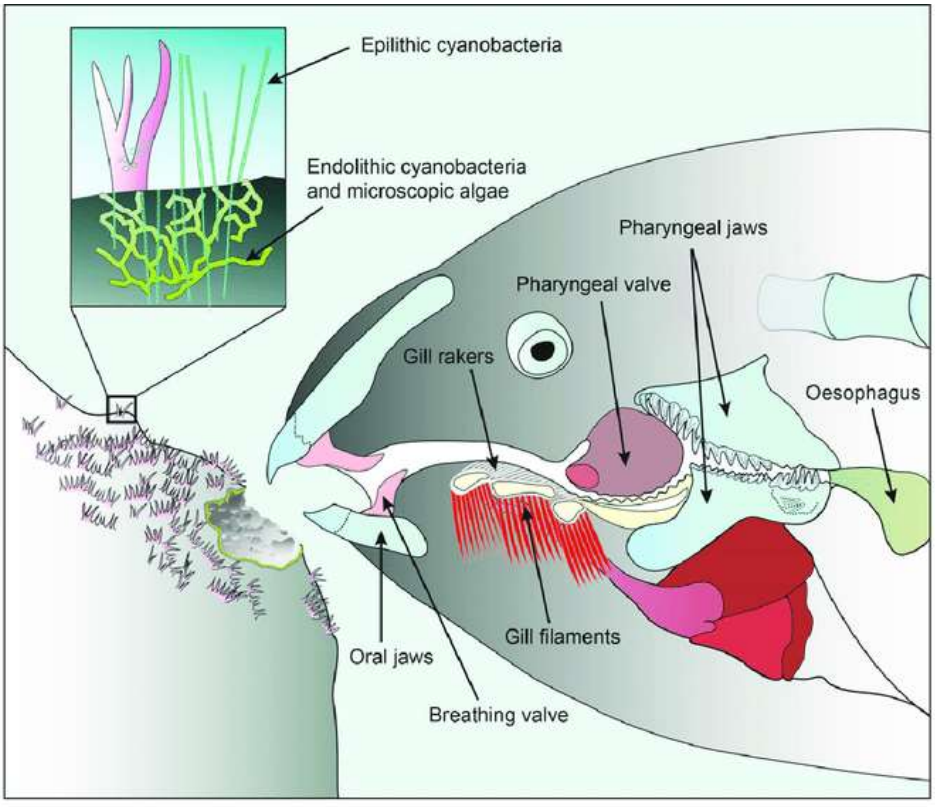

Figure 4. Morphology of Parrotfish head [28]

4. Nutrition and Feeding Behavior

• Diet Composition

Parrotfish mainly rely on benthic algae as their source of food, with some species being corallivores and feeding on live coral tissues, while others feed on various algae and detritivores. Feeding behavior is related to the seasons and food resources in terms of availability, hence parrotfish adjust to the conditions of the environment. This versatility affects ecosystems; herbivorous parrotfish help keep algae levels in check, which is good for reefs but can be detrimental to the corals and the structure of the reef [29]. Changes in the reef dynamics are also influenced by bioerosion and sediment production, which is brought about by corallivorous species. Juvenile parrotfish are more engaged in benthic feeding to bottom debris and small invertebrates that help them grow and move around the reefs without much competition with adult parrotfish [30].

- **Feeding Mechanisms and Strategies**

Parrotfish feeding habits are quite peculiar and are associated with their beak-like teeth that are adapted to scraping algae off coral reefs. This beak is formed by the tight cementation of the teeth to form plates which they use to scrape or bite off pieces of the substrate such as algae and corals. This adaptation not only enables parrotfish to feed on the resources that are out of reach to many other organisms in the reef habitat but also contributes towards bioerosion and sedimentation in the coral reef community [31].

Another interesting feeding characteristic of parrotfish is that the parrotfish grinds the food that it consumes in its mouth into a paste-like substance in Figure 5. This is due to their pharyngeal teeth found in the throat where they grind the ingested substance into small particles to enhance digestion and absorption of nutrients. This grinding activity is very effective in breaking down the algal cell walls, and coral skeletons to get the best out of the food for the parrot fish.

The feeding habits of parrotfish are diurnal meaning that they feed during the day and are least active at night. This is believed to be done to escape from the night hunters and also to fit their feeding habits with the amount of light that is favorable for the growth of algae. In addition, parrotfish exhibit territorial feeding and where this occurs, they will drive away other herbivores fishes to protect the feeding areas for food.

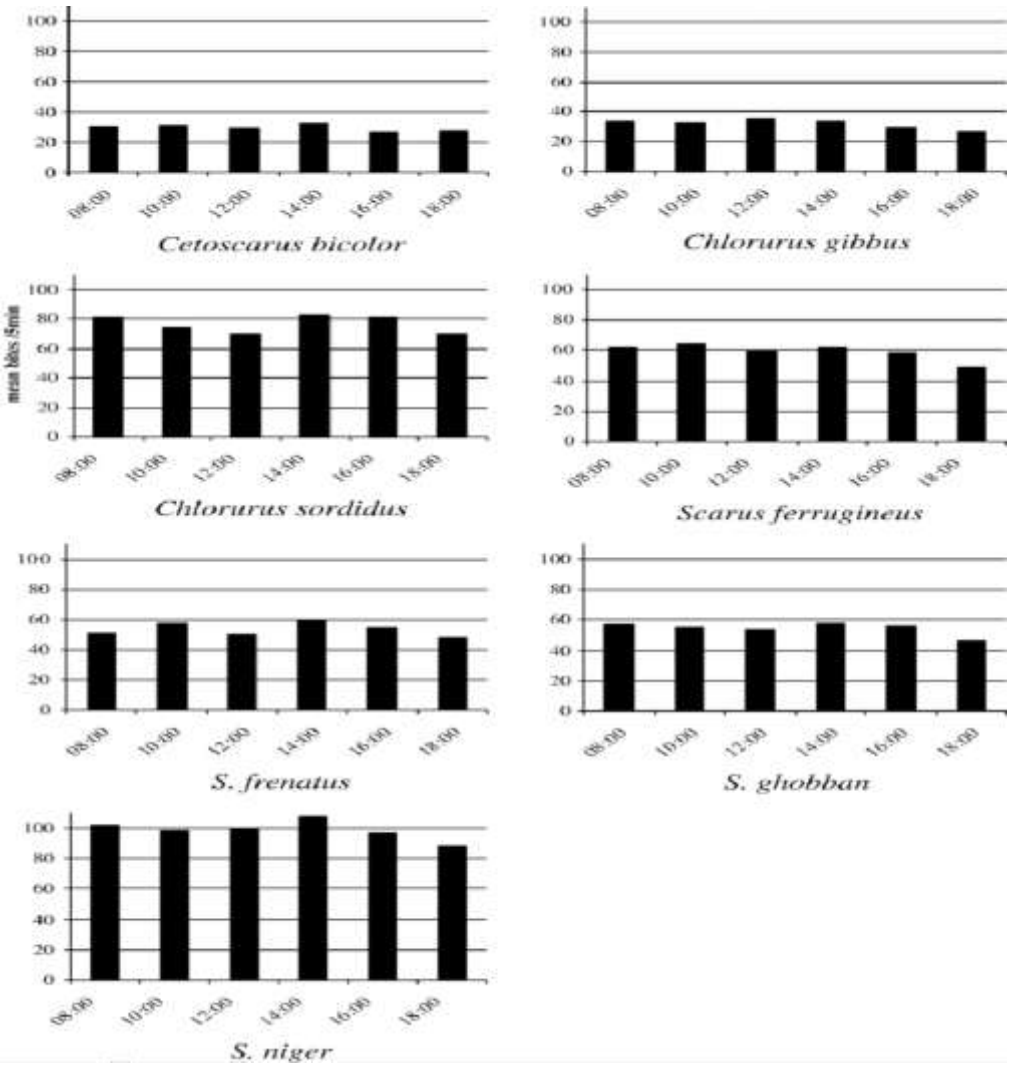

Figure 5. Daily feeding Mechanisms of Parrotfish [32] [https://www.researchgate.net/figure/Daily-feeding-patterns-of-parrotfish-species-averaged-over-all-sites-on-the-Northern_fig2_248248731]

- **Impact on Coral Reefs and Algae**

Parrotfish feed predominantly on bottom algae which grow on the structures formed by coral reefs. Algae are consumed by parrotfish which if allowed to grow outcompete corals for space and light which hampers the growth and recruitment of corals. This grazing activity is important to prevent algal overgrowth which is very destructive to the coral reef formations. Thus, it has been ascertained that the parrotfish, which are fond of feeding on algae, have detrimental impacts on the algal cover and a beneficial influence on the corals [33].

In addition to controlling algal growth, parrotfish feed on live coral polyps that are present on the coral reefs. While this feeding behavior may seem to be negative, it is an aspect of bioerosion that is essential in the management and growth of the reefs. Feeding by parrotfish results in the production of fine coral sand because they gnaw coral materials. This bioerosion activity contributes to the construction of reef frameworks and the delivery of sediment for reef construction and island development [34].

Parrotfish are day feeders and are most active during the day and mostly rest during nighttime. They maintain this behavior to control their impacts on algae and corals, which are two antagonistic organisms in their ecosystem. It is important to note that this pressure from parrotfish is crucial in providing the necessary open space for coral recruits to settle and develop [35].

- **Role in Nutrient Cycling**

Parrotfish have a role to play in the cycle of nutrients in the coral reef ecosystem. They are primary consumers that feed on algae and other organic substances, which helps in digestion and excretion, and hence, are involved in nutrient cycling. The process of ingestion and regurgitation of calcium carbonate aids in replenishing the carbonate in the reef which plays a role in the building of the reef [36].

The feeding activities of their larvae produce fecal pellets containing fine particles which are ingested by other reef organisms; this promotes benthic microorganisms and therefore increases the productivity of the reefs. Parrotfish always released the nutrients they consumed through their faeces over the reef, and this was beneficial to nutrient cycling and reef status [37]. Furthermore, parrotfish have ecological responsibilities of reducing large organic matter into smaller particles to support the producers such as algae and seagrass. It is crucial for sustaining production and organization in nutrient-limited tropical seas. Knowledge of parrotfish diet and feeding behavior is important to appreciate their role in regulating algae, bioerosion, nutrient cycling, and other factors that influence the health, recovery, and productivity of coral reef ecosystems.

5. Reproductive Behavior

Reproductively, the parrot fish is sending out protogynous hermaphrodites which are individuals that can switch sex from female to male. Some of the most interesting features of the reproductive biology of parrot fish are as follows: Knowledge of their mating systems, their reproductive behaviors, and spawning habits provides insight into their reproductive physiology.

- **Mating Systems and Reproductive Behavior**

Parrotfish is mostly a sequential hermaphrodite which means that it is born as a female and turns into a male when it is fully grown. This type of sequential hermaphroditism is usual among many reef fishes and depends on social and environmental conditions. Parrotfishes are hermaphrodites and they are also known to display some form of social behavior that is commonly referred to as harem, which comprises a large male fish and several female fishes. These harems are created and sustained through force, and one must defend his harem and the females from other males [38].

Polychromatism

Parrotfish have an interesting pattern known as polychromatism, in which the fish can occupy different color variations and patterns during their development. Young parrotfish may have a different coloration from the older ones, especially the male parrotfishes while the females may be differently colored from the young ones or other mature females [82]. That could be because they are protecting themselves from predators; the young parrotfish are less conspicuous and do not have the same flamboyant colors as the mature ones.

The color changes in parrotfish may also point to this part of their reproductive life and their ability to fend off competitors. In mature individuals, the colors become even brighter and the patterns become even more intensified like stripes [83]. Thus, in species, for instance, the stoplight parrotfish, the juvenile fish are usually brown or grey with white spots. During reproductive maturity in males, they assume bright and shiny red, green, and yellow colors. This coloration informs their prospective mates and competitors of their class or rank**.**

In parrotfish, reproductive success is size and dominance-related, and this is determined by the fish in the social group. Big people especially men are more reproductive and are likely to regulate the access of females. However, small males can also use sneaker tactics to approach the spawning events and fertilize eggs because they mimic females [39].

Mating behaviors of the parrot fish are also affected by factors such as the lunar cycle, water temperature and food supply. Recruitment events are associated with certain environmental conditions that favor the survival of larvae and their recruitment to the substrate. These strategies give reproductive success and immortality of parrotfish in their environment [40].

- **Spawning Patterns**

Male and female parrotfish lay eggs in water at specific times and locations that are controlled by lunar calendars, and the most spawnings are recorded during full moon. This coordination is useful in enhancing the probabilities of fertilization and survival of the larvae in relation to water characteristics and the activity of predators [41.
Reproductive activities within coral reef ecosystems entail several parrotfish species that are natives of specific regions of the reef. These aggregations perform various roles such as mate attraction, gamete dispersal and predator avoidance which play a role in genetic variation as well as population recovery. Parrotfish's reproductive capabilities vary with species, cycle, habitat and population density. Some of the species are seasonal breeders while others breed at any time of the year depending on the conditions [42].
The awareness of these reproductive strategies is helpful in the conservation of the coral reef habitats and other related species.

- **Larval Development and Recruitment**

Parrotfish reproduce through oviparous fashion where the eggs are planktonic which exist in water until they develop to benthic young ones in Figure 6. Some of the factors that influence the development of the larvae include water movement, temperature of the water, and food in the sea. Dispersal of larvae is therefore determined by water currents, and this determines the distribution and recruitment of larvae [43].

In the parrotfish, the changes in the morphology and physiology of the larvae also occur during the pelagic phase of the life cycle of parrotfish and the larval development. They build such structures as fins and swim bladders for floating and moving in the water and at the same time searching for a suitable habitat [44].

Recruitment to reef habitats is a significant life history event for parrotfish as it defines its survival and replenishment of the adult population. Chemical signals and habitat complexity are other factors that determine the ability of the larvae to locate the right reef habitats for settlement. Recruitment assists in restocking parrotfish and also the coral reef habitat.

- **Childcare and Juvenile survival**

Some of the species of Parrotfish do not guard their young ones but there is some sort of parental care. Female parrotfish may choose the right substrate and water conditions for eggs deposition and larvae development. Furthermore, males of the species in spawning aggregation may guard the nesting areas and guard eggs and larvae against predators [45].
During the development of juvenile parrotfish, the species is vulnerable to predation, competition, and other factors in the environment. Higher constructs like coral reefs may be used by juveniles to avoid predation and get food to enhance their survival. In addition, juveniles are commonly encountered in groups or shoaling which has benefits in areas of protection and learning.The distribution and abundance of juvenile parrotfish are determined by aspects such as structure of the habitat, availability of food, and presence of predators or competitors in the reef area. The factors of the coral reef habitat such as food and structure enhance the chances of survival and development of juvenile parrotfish [46].

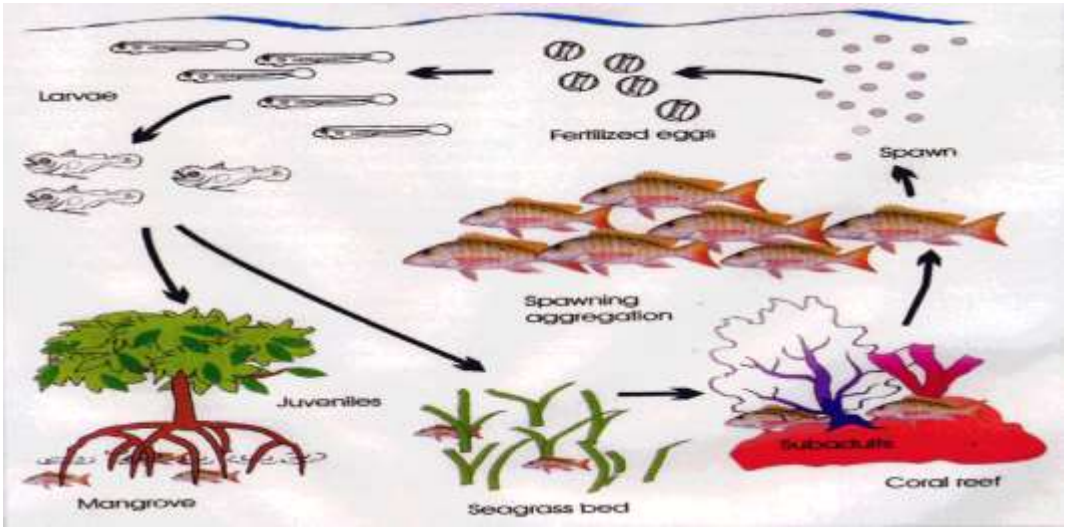

Figure 6. Reproductive cycle of Parrot Fish. [47]

6. Social Structure and Behavior

- **Group Dynamics and Hierarchies**

Parrotfish are social animals, and they are found in small groups or large schools depending on the type of parrotfish and the habitat. Some of the uses of group formations include feeding, protection from predators, reproduction and signaling. Thus, parrotfish may enhance feeding rates, exchange information on feeding grounds, and enhance the chances of survival [48].

Parrotfish social organization is therefore influenced by factors such as the structure of the habitat, food availability and predation. It is expected that structures such as reef systems that provide food and shelter are likely to foster social gathering and group harmony. Moreover, predators may increase the degree of grouping and synchronization of the movements of the individuals to minimize the chances of predation [49].

Hierarchies

The parrotfish has high degree of social differentiation particularly in the mating where the dominant fish has control over the resources and the females for reproduction. Males employ forceful actions to establish dominance hierarchy, with the dominant individuals protecting their territories and resources, such as food and females [50].

In harems, dominant males maintain their status through aggression and physical combat with other males. These interactions include chasing, display of bright colours, and fighting to subdue other males and establish control over the females [51].

Subordinate individuals within the parrotfish groups may employ various reproductive strategies in a bid to improve their fitness. Sneaker males for example mimic females in coloration and behavior in order to get close to spawning events and fertilize eggs without much hindrance from other dominant males. This strategy helps subordinate males to escape from the pressures of dominant males and increase their reproductive potential.

Behavioral Plasticity

But parrotfish are not fixed in their behaviour and they can easily alter their behaviour depending on the circumstances and interactions. Such behaviors include distribution of foods, predation pressure and social interactions with the other animals of the same species. This flexibility helps parrotfish to remain functional in their ecological niches even when there are changes in the level of stress in dynamic reef ecosystems [52].

Therefore, the social structure and interactions of the parrot fish include group living, dominance-subordination and flexibility. Such interactions are crucial in the organization and existence factors of parrotfish in coral reef environments.

- **Territoriality and Aggression**

These two aspects of social organization characterize the organization of the parrot fish and its relations in the coral reef environment. Knowledge of these aspects gives an insight into the intriguing existence of these fish that inhabit the reefs.

Territoriality

Parrotfish are territorial, especially the dominant male that is in charge of guarding the areas for spawning and foraging. Limits of the territories are marked by different means, for example by coloration, size and aggressive actions. Erect male individuals also constantly guard their areas against potential threats, such as other males and potential predators.

Parrotfish defend territories for several reasons, including resource procurement, sexual selection, and reproduction. The territorial males choose the best areas with the most optimal conditions for feeding and nesting as well as for courtship and spawning. Through the control of these resources, the dominant people are in a position to improve their reproductive rate and remain relevant in the population [53].

Aggression

It is also worth mentioning that aggression is an essential element of social interaction among parrot fish, especially when it comes to the defense of the territory and mating. This involves charging, biting, finning, vocalizing, and other postures that are employed to dominate or defend a territory or to gain access to a female. This is true because aggression is most common during the breeding season because many males are competing for access to females.

Larger and older males perform displays of aggression on other males to establish their dominance and to ward off other males from their harem. These displays include visual displays such as courtship and aggressive displays, and physical displays that involve the use of physical force by the dominant individuals to control access to these sites [54].

It is, however, important to note that aggression in parrotfish is not only restricted to conspecific interactions but can also be observed in competition with other species and while escaping from predators in Figure 7. Parrotfish may chase other reef species, defend their territories from other parrotfish and other species and may also compete for food. In the same way, parrotfish might also exhibit aggressive behaviors towards other probable predators to avoid being attacked and guard themselves from predation [55].

Ecological Implications

Both territoriality and aggression are critical in determining the structure of the parrot fish population along with its impact on the coral reef system. Therefore, through defending territories and asserting aggressive behaviors, parrot fish can control the population densities and help preserve the integrity of the reefs and increase the species' diversity in the communities. Further, territoriality and aggression are instrumental in the reproductive success and genetic fitness of dominant parrotfishes, which in turn maintain the overall long-term stock of parrotfishes [56].

Therefore, territoriality and aggression are inherent aspects of the social organization and behavior of parrot fish and play crucial roles in the species' social dynamics, reproductive behaviors, and ecological functions within the coral reef habitats.

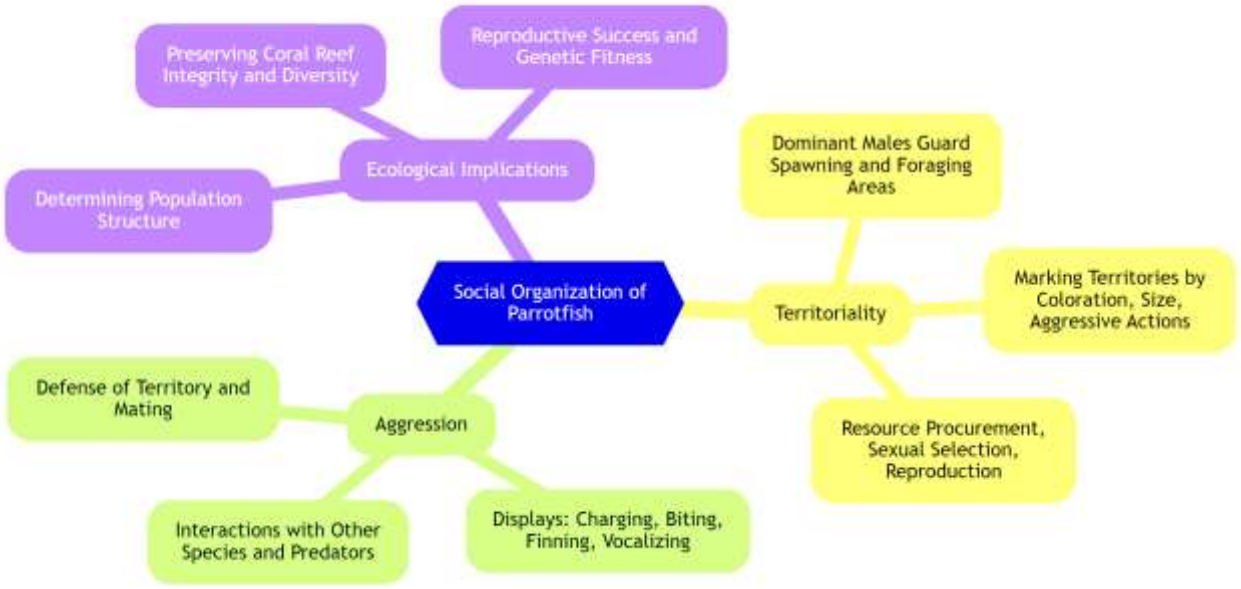

Figure 7. The social organization, territoriality, aggression, and ecological implications of parrotfish in the coral reef environment.

- **Communication Methods**

Communication is a fundamental aspect of the social structure and behavior of parrot fish, facilitating interactions among individuals and influencing their ecological roles within coral reef ecosystems. Such information about the different modes of communication employed by parrotfish is rather helpful in the discovery of their habitat.

Non-Verbal Communication

Another important category of communication that is evident in the interaction between parrot fish is visual communication, where these fish employ various forms of visual cues to pass information to other fish of the same species. Another obvious aspect of the communication media is coloration; parrotfish have bright and contrasting coloration patterns that have multiple uses. Males that are bright in contrast to other males scare off competitors and attract females; females and young ones are dull and blend to avoid being seen by predators [57].

Other visual signals that are employed by parrotfish in the communication of intentions and social status include postures and movements of the body. Males might attack and become aggressive and develop erect dorsal fins and gill flaps to keep off other males and to guard their territories.

Audio Cues

As with visual cues, vocal communication has not been studied as extensively but it is also used by the parrot fish in their social lives in Figure 8. There are several sounds that parrotfish are capable of producing such as clicks, grunts, or pops with the help of organs such as swim bladder or pharyngeal teeth. These acoustic signals are thought to convey information about the identity of the individual, their reproductive state, and the ownership of a particular territory [58].

In parrotfish, the use of sound is most preferred during the breeding period where the male parrotfish uses sound to call on the females and also to chase away the rivals. These sounds may be used in courtship displays or territorial announcements, which in essence, tell potential mates about their reproductive state and health. Furthermore, parrotfish may employ sound in the following ways: to guide the position of a group, to locate areas where food is present, and to interact with other parrotfish in stained water.

Chemical Signals

The other form of communication that is employed by the parrot fish is chemical signals which are employed for identification of the sexual partners, to mark territories as well, and to avoid predators. Some of how parrotfish communicate includes releasing chemical signals in the water and these signals may include information about the fish's identity, its reproductive status, and the quality of the surrounding habitat. These chemical signals play a crucial role in regulating social interactions and group harmony within the parrotfish shoal [59].

There are chemical substances secreted by dominant males that may be used to warn other males not to encroach into the territories that they have marked as their breeding grounds. There are also chemical signals used in spawning to attract the potential mate and synchronize the reproductive actions of the individuals that are in the spawning groups. Chemical communication is also used in predator avoidance, parrotfish can identify and respond to alarm signals which are chemicals emitted by injured or stressed conspecifics.

Figure 8. The various forms of chemical communication employed by parrotfish

Ecological Importance

The different communication methods used by the parrot fish species have important implications for the behavior, social structure, and function of the coral reef ecosystems. Parrotfish use communication in the organization of the group, management of the dominance, and reproductive rate. In addition, it is said that parrotfish use communication to reduce predation risk, distribute resources, and perform cooperative behaviors that help maintain the stability of the parrotfish population within the changing reef environment [60]. In sum, communication methods play a crucial role in the social structure and interaction of parrot fish with other organisms in the coral reef ecosystem.

7. Conservation Status and Threats

• Current Population Trends

Population Declines

The parrot fish population is in danger of extinction due to climate change, fishing, water pollution, and loss of its habitat. These have led to decreased coral cover, loss of habitat, and a decrease in food stocks for the parrotfish [61].

Habitat Loss and Degradation

The main factors that have led to the destruction and loss of the parrot fish are pollution, sedimentation, bottom trawling, and coastal development in Figure 9. These threats are compounded by coral bleaching and ocean acidification which leads to reef degradation and availability of suitable habitats [62].

Conservation Efforts

The measures that have been taken to protect the parrot fish and coral reefs include the creation of MPAs to limit fishing and the destruction of habitats. Another advantage of community-based conservation programs is that the community is engaged in conservation, management, law enforcement, and rehabilitation [63].

But some things must be done to protect the parrot fish and coral reefs in the future. Thus, the cooperation of governments, NGOs, scientists, and local communities is imperative to preserve the species and their living environment.

• Threats from Climate Change and Human Activities

The conservation status of parrot fish is profoundly influenced by various threats, with climate change and human activities posing significant challenges to their survival and the health of coral reef ecosystems. It is important to know these threats to design proper measures to preserve the habitat of the parrot fish.

Climate Change Consequences

Climate change increases the threats to parrot fish and coral reefs, which causes bleaching of corals and decreases coral growth as the sea temperatures rise and the ocean becomes more acidic. Climate change also increases the frequency of hurricanes and cyclones which can harm coral reefs and destabilize the ecosystem [64].

Human Activities

Climate change has negative effects on human beings, and human activities also cause pollution and deterioration of the reefs. These activities include overfishing, destructive fishing practices, coastal development, sedimentation, and pollution from agriculture and industry are the major factors that put the existence of parrot fish and coral reefs at risk. This is because chemical pollutants worsen the health and behavioral patterns of marine organisms including parrotfish [65]

To counter these threats, efforts have to be made to mitigate the effects of climate change and the over-exploitation of fish stocks and to develop ways of managing pollution and the coastal zone. These two types of fish and the coral reefs that they inhabit, need to be safeguarded from human interference to allow them to survive and continue to be beneficial to the environment.

- **Conservation Efforts and Management Strategies**

Conservation and management play a role in addressing several threats that are a menace to the existence of the parrot fish and the condition of the coral reefs. This section discusses different methods and actions that have been taken to mitigate threats and promote the conservation of these valuable reef dwellers.[66]

Marine Protected Areas (MPAs)

A useful strategy in the conservation of parrot fish is the formulation and implementation of the Marine Protected Area Strategy. MPAs are protected zones in that fishing and other activities may have negative impacts on the environment, for instance, the destruction of habitats is prohibited by law. MPAs are also beneficial to other species and habitats, as overfished species such as the parrotfish are protected. Such practices in the affected regions encourage the sustainable utilization of natural resources [67]. The optimal MPAs should protect critical areas such as breeding and feeding grounds that will be essential to parrotfish at some stage in their life cycle.

Fisheries Management

The overfishing of the parrotfish needs to be controlled through correct fisheries management practices that will assist in the control of the species. This includes the setting of quotas to the number and size of fish that can be owned, the number of fish that must be kept as breeding stock, and the times at which ownership is prohibited to prevent the depletion of the breeding stock. The management of fisheries also needs to consider the condition of parrotfish stock and should include actions that are aimed at reducing bycatch and the effects of fishing equipment on the surroundings. Engagement of the community in the decision-making and the stewardship of the measures has been good in enhancing compliance and sustainable use of parrotfish resources [68].

Habitat Restoration

Measures like the restoration of habitats contribute to the improvement of the ability of coral reefs to withstand stress factors thereby increasing the number of parrotfish. Some of the restoration measures may include coral gardening, reef construction, and eradicating certain species that are deemed destructive to the reefs. Such measures help increase the level of challenge of the environment, improve the quality of water, and provide more avenues for the parrotfish and other species in the reef. In the process of habitat restoration, there may be the involvement of research institutions, NGOs, community, and government departments to ensure the sustainability of the project [69].

Climate Change Mitigation

Another factor that has to be considered in the management of parrot fish is the future, which is currently threatened by climate change. Some measures that can help to prevent climate change's effects on coral reefs include cutting greenhouse gas emissions, promoting renewable energy, and increasing carbon speciation. In addition, measures taken at the area level to enhance the reef's sustainability, for instance, the protection of herbivore fish species like parrot fish that feed on algae that is bad for the corals are also important. However, to do this, it is imperative to continue to observe and study the coral reef to determine the alterations that occur in the reef habitat and to establish strategies that would address the new climatic effects [70].

Public Awareness and Education

Among the measures that have to be taken is sensitization of the public on the protection of parrotfish and corals. Sensitization, capacity building, and dissemination could help in the creation of a sustainable and environmentally conscious society for the people, visitors, and other users of the environment. Therefore, the awareness of parrotfish and coral reefs in the ecological, economic, and cultural sense can increase public awareness of conservation measures and practices for the protection of the reefs [71].

Policy and Legislation

It is therefore necessary to improve on the existing policy and legal measures that would protect the parrot fish and their environment. This includes the enforcement of existing environmental legislation, the development of new legislation to meet emergent concerns, and the integration of conservation goals into other areas. Other sources include national legislation and international treaties and agreements, such as The Convention on Biological Diversity as well as regional fisheries management organizations to perform the organization of the conservation activities and exchange of the experience between the countries.

Therefore, the following are some of the broad strategies that should be put in place for the conservation of parrot fish: Conservation tools include MPAs, selective fishing, habitat restoration, measures against climate change, awareness, and

sound policies. If properly employed, such measures can help in enhancing the protection of parrotfish and the general welfare of coral reef systems.

- **Protected Areas and Legislation**

Some of the threats that threaten the conservation status of the parrot fish include; therefore there is the need to have robust protected areas and legislation to protect the species and the coral reef habitats. Such threats should be combated, and the reef habitats enhanced through MPAs and good legislation.

Marine Protected Areas (MPAs)

The only way to cease the extinction of the parrot fish through fishing, destruction of their habitat, and pollution is through Marine Protected Areas. MPAs are the geographical areas where people's interaction with the environment is limited in some way to conserve biological diversity and its underlying processes. These areas are particularly effective when located in a manner that would embrace important habitat features such as breeding, feeding, and migration grounds [72].

Previous research has demonstrated that MPAs have led to an increase in biomass and species density in the protected areas and possibly the peripheral zones of protected areas. For instance, it has been confirmed that MPAs when well managed can increase the fish stock, the parrotfish since they are protected from fishing. For instance, the Great Barrier Reef Marine Park in Australia is a good example where a system of MPAs has been set to protect the many species within the reef, including different types of parrotfish [73].

Legislative Measures

Other sound legislation still helps to protect parrot fish apart from MPAs, as they continue to have a significant impact. The activities that are destructive to the coral reefs are well regulated by national and international laws. Some of the measures include the prohibition of some types of fishing, the conservation of breeding areas, and the prevention of water pollution.

Parrotfish should not be exploited, and this can only be done through the enactment of fisheries management legislation. This may involve the catch quotas, the minimum size, and the prohibition of fishing during a particular season to conserve the breeding stock. Furthermore, gear restrictions can minimize the impacts of destructive fishing practices, including trawling and blast fishing. In the United States, the legal instruments that define the management and conservation of fishery resources are the Magnuson-Stevens Fishery Conservation and Management Act, which may have measures that could be advantageous to reef fish such as parrotfish [74].

International Agreements

Other aspects that have been found to influence the conservation of the parrot fish include international agreements. CBD has goals in the creation of protected areas and the sustainable use of resources of the sea. CBD's Aichi Biodiversity Targets, particularly Target 11 seek to protect at least 10% of marine and coastal areas by the year 2020 and therefore contribute to the establishment and efficient management of MPAs [75].

Another major international instrument is the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), which controls trade in endangered species. At present, parrotfish are not listed in the CITES list, but this convention is an example of how the trade in endangered species can be controlled, and if necessary, parrotfish can be listed in this convention.

Community Involvement and Enforcement

It is important to note that compliance should be observed with the protected areas and the laws that support them. This is usually time-consuming and involves a lot of resources and support from the public. Involving the local people in the management of the MPAs can also help in increasing compliance and stewardship. Decentralized management practices engage the locals in the conservation process, resource management, and the implementation of laws leading to better management [76].

Education and raising awareness of the public are also important factors in the promotion of conservation. These initiatives can help develop a conservation attitude and appropriate behavior from the public and stakeholders by raising awareness of the ecosystem values of parrotfish and coral reefs.

Therefore, it can be stated that the presence of protected areas and appropriate legal provisions are important to preserve the species. Thus, the threats to coral reef ecosystems can be mitigated and eliminated with the use of MPAs that are supported by national and international laws. Both the compliance of local people and the participation of local people are important aspects of the measures that will help in the conservation of the parrot fish and their habitats.

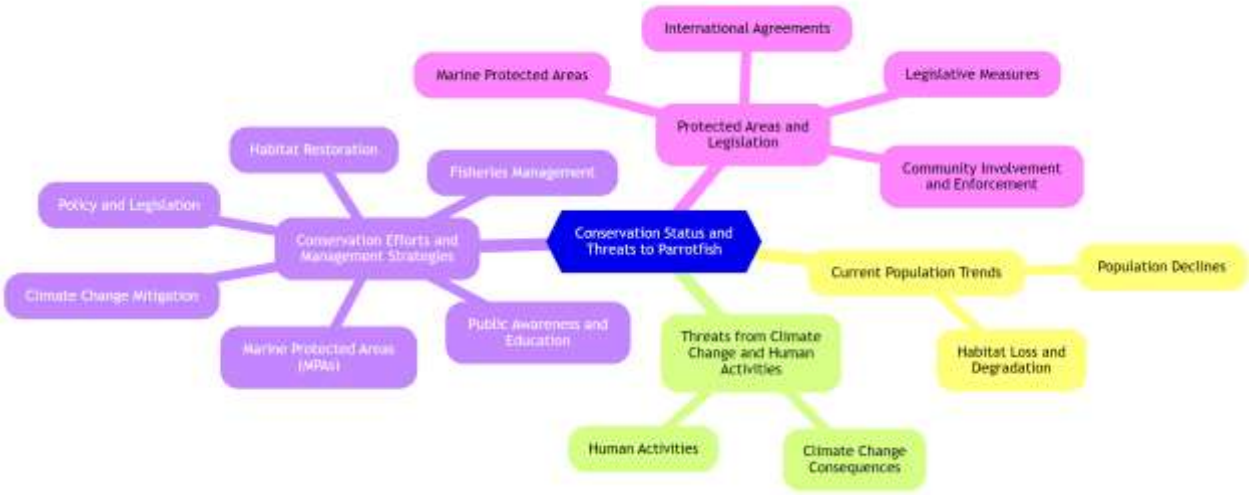

Figure 9. The conservation status, threats, and management strategies related to parrotfish

9. Future Directions in Parrotfish Research

Observation of parrot fish as the object of study as one of the representatives of the coral reefs can become an important source of new information about marine life and the ways of its protection. This section focuses on the rest of the research questions, the effects of climate change, and new themes and approaches to parrotfish studies.

Gaps in Current Knowledge

Nevertheless, there are several gaps in knowledge about the ecological and behavioral characteristics of parrot fish. Specific information about this species' life history characteristics such as growth rate, age, and generation length are scarce. These traits are essential for population modeling and species management of the population [77]. Also, there is scarce information on the behavioral ecology of the parrot fish such as territoriality, social relations, and breeding patterns. It can show how these behaviors affect population trends and certain key niches. The population of parrot fish also has no information on genetics. Information concerning the structure of genes and their distribution within populations can inform about the populations' ability to respond to changes in the environment and which of the conservation strategies needs to be applied. It is also important to note that although the effects of coral bleaching and habitat loss are already established, there is still more research needed to be done to understand the effects of other forms of habitat degradation such as pollution and invasive species on the parrot fish.

Potential Impacts of Climate Change

Parrotfish are under the threat of climate change and its impact on the coral reef habitats that they dwell in. Possible areas for further research are: examining how much parrotfish is heat-tolerant to determine its ability to survive in sea temperatures due to climate change [66]. Field studies investigating the impacts of thermal stress on parrotfish and whether such species can adapt to rising water temperatures could shed light on this facet. Subsequent studies should also explore the effects of climate change – ocean acidification on the feeding, growth, and skeletal development of parrotfish [42]. Understanding how changes in the chemistry of seawater influence the rate at which algae are eaten and the amount of calcium carbonate used in building parrotfish could enable the prediction of the future effects on these fish [7]. In addition to considering the effects that global warming and ocean acidification have on the physiological condition of parrotfish, there is also a point in exploring how warming and acidification may interfere with the other important relationships parrotfish have with other species inhabiting the reef. Disruptions of such ecological interactions could result in multiplier effects on the stability of coral reef communities [78]. Increased understanding of changes in parrotfish community populations could help in the prediction of climate change impacts on coral reefs more generally. In general, enhancing our knowledge of how various aspects of climate change affect parrotfish in particular will be essential for protecting these ecologically vital species and thereby perpetually stabilizing the world's increasingly vulnerable coral reef ecosystems.

Emerging Research Areas and Technologies

The techniques in research are being enhanced and developed, which is creating new opportunities to investigate parrot fish in Figure 10. Remote sensing and GIS can complement the evaluation of parrotfish habitats and the distribution of the species. These technologies can help in surveying the large area of the coral reef and monitor changes in the environment at a small scale. Bioacoustic monitoring can be applied to the observation of parrotfish, their interaction, and activity. This technology can aid in determining which calls correspond to certain activities, feeding, mating, and fighting. Some new trends in genomics and molecular biology can give the possibility to investigate the genetic organization of parrotfish. DNA barcoding and genomic sequencing can help understand population structure, phylogenetics, and

adaptation [79]. Coupling climate models with ecological data can assist in the ability to forecast how parrotfish populations will be affected by climate change in the future. These models can be used to determine which species and habitats are most at risk, and where the conservation actions should be directed. The involvement of the public in the research on parrotfish through citizen science can also assist in the collection of data as well as increase awareness of the problem. Private persons can also provide useful data on parrotfish activity, presence, and environmental conditions [80]. Therefore, future research on parrot fish should fill the gaps, consider the effects of climate change, and adopt the technologies to mitigate the loss. Hence, gaining more knowledge about these important reef species is crucial for the preservation of coral reef systems in the future.

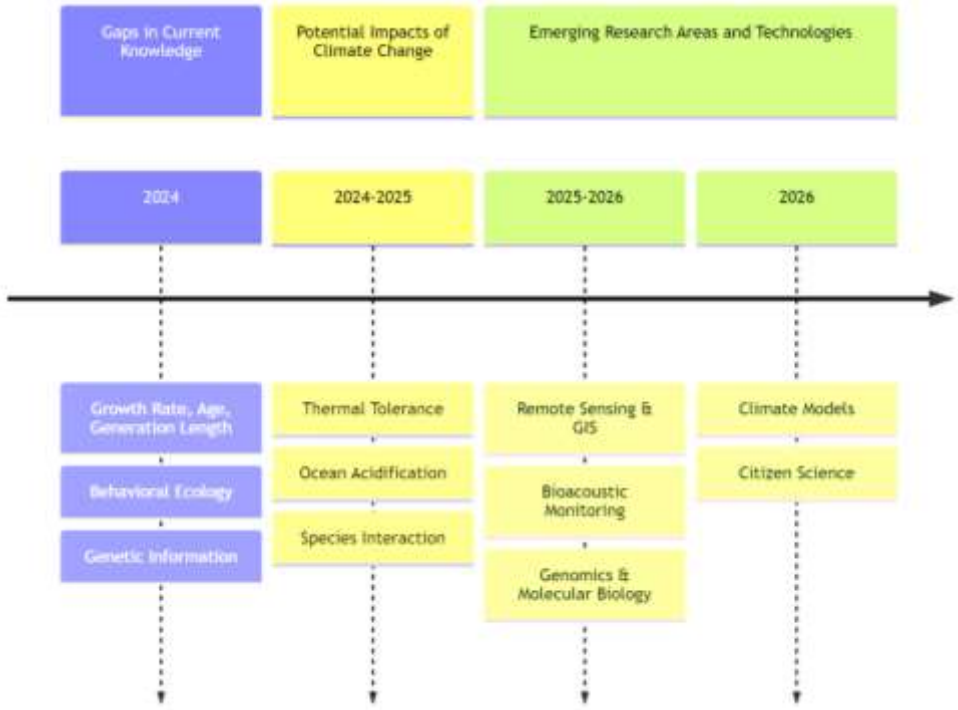

Figure 10. Parrotfish research overview.

10. Conclusion

This study on parrot fish therefore calls for further studies on these fish species and their conservation in the marine environment. From the knowledge which has been acquired from the study of their life history a lot of understanding has been gained on their function in the health of corals. For example, their feeding habits as herbivores that feed mainly on algae are important in supporting the coral reefs since the growth of the algae is detrimental to the coral and the structure it forms. This role underscores the significance of these species as the keystone species that are known to set the tempo of the ecological processes in the reef environment. However, there are still a lot of questions about various aspects of their biology and ecology that remain unanswered. These are the life history traits, behavioral ecology, and genetic stocks which are still unknown and thus the management and conservation of the species become difficult. Such gaps need to be filled to create the proper conservation measures that would be suitable for the life cycle of parrot fish.

However, climate change is a factor that threatens the lives of parrot fish and their habitat. Hence, their thermal tolerance and effect of ocean acidification should be investigated to understand how these species will be affected by climate change. It is important to know how parrotfish behaves, physiologically and in terms of population density by identifying the different environmental factors that influence the fish.

The advancement in technology provides a hopeful future for the improvement of research and conservation efforts. The methods of remote sensing, bioacoustics, and genomics are valuable in providing the life history of parrotfish and their reaction to different stress factors at multiple spatial and temporal scales. In this manner, the researchers are in a position to gain more knowledge on the ecology of parrotfish and find more appropriate methods of conserving them.

Due to climate change and loss of habitat, parrot fish continue to be considered a sensitive species in marine systems. It is crucial since the protection of these species is not only significant for the genetic pool of coral reef species but also for the numerous functions and values of such habitats. Thus, further research and joint protection actions are required to preserve parrot fish and their environment for as long as possible.

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