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Review

Parrotfish: An overview of ecology, nutrition, and reproduction behaviour

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ABSTRACT

The temporal and geographical variety of population dynamics in coral reef fish profoundly affects environmental resources.Parrotfishes are a group of about 90 fish species regarded as a family (Scaridae) or a subfamily (Scarinae) of the wrasses. The Indo-Pacific has the highest species richness in this category, with around 95 species. They are found in coral reefs, rocky coasts, and seagrass beds and can play a significant role in bioerosion. Most parrotfish species are herbivores, feeding mainly on epilithic algae. The development of parrotfishes is complex and accompanied by a series of changes in sex and color (polychromatism). In this review, the biological and ecological studies, the search for seasonal food, and finally, the breeding of parrotfish were shed light and clarified. Also modern tracking methods have been highlighted to monitor the migration of parrot fish. Finally, highlighting the sight of the annual seasonal stampede of parrotfish migration to Farasan Island.

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1. Introduction

Longnose parrotfish (*Hipposcarus haread*) routinely aggregate in large schools yearly during the spring (Gladstone 1996) in a shallow lagoon in the Farasan Islands of the Southern Red Sea. This assemblage has been known to locals for over two centuries and inspired Saudi Arabia's annual Hareed Festival 7 to 12 schools landed in the lagoon between April 7 and 13, 2012. Schools were 3–4 m in diameter and contained approximately 200–500 tightly-packed individuals (20–30 cm total length). All fish displayed pale, initial phase coloration except for one terminal-phase individual per school. No schools of parrotfish were observed in open waters outside the lagoon area. In preparation for the Hareed Festival, when most schools have arrived on the 5th day of the aggregation, local fishermen trap 3,000–5,000 parrotfish in the lagoon. Following tradition, hundreds of local people then gather along the shore. Equipped with nets, they await a starting signal and then rush into the lagoon (Fig. 1c). Whoever catches the largest biomass is awarded prize money from the prince of the Farasan region, again following a long tradition. Caught fishthat seems unripe condition (no running eggs or milt observed), are given away as gift to family, and friends, consumed by the winners, or discarded since selling under festival rule is prohibited. After approximately 60 min, no live fish remains in the enclosed area. Despite this intense harvesting, the aggregation still arrives every year. The Farasan Islands are the only known location in the Red Sea where parrotfish aggregate in an above-described manner. It is unclear why and how this species aggregates in this particular lagoon at a specific time every year. The observed behavior is entirely different from any other aggregation of parrotfishes (Sadovy de Mitcheson and Colin 2011) and, at this stage, does not appear to be a spawning aggregation. Interestingly, the aggregation always begins one day after the full moon, coinciding with the annual coral spawning event, as recently discovered (Bouwmeester et al. 2012). Whatever the reason, the predictability of this annual aggregation forms the basis of a long-running harvest event and cultural festival.

2. Biological and environmental studies concern the parrotfish

2.1. Biologic study

Farasan Islands (16°43′44.16″N, 42°4′24.47″E) in the southern Red Sea's Longnose Parrotfish (*Hipposcarus harid*) gather in big schools once a year in the spring (Gladstone 1996). The annual Hareed Festival in Saudi Arabia is conducted in honor of this meeting, which has been well-known to the country's people for the past two centuries.Some 200–500 individuals (20–30 cm total length) were estimated to be crammed into 3–4 m diameter schools. Each school contained only a single fish in the terminal phase, the only exception being a single pale-colored fish in the early stage. There were no groups of parrotfish seen outside of the lagoon. As part of preparations for this year's Hareed Festival, local fishermen capture 3,000–5,000 parrotfish in the lagoon on the fifth day of the aggregation, when most schools have arrived. People from around the region then converge on the beach per custom. They wait for a signal and then rush into the lagoon, armed with nets. The prince of the Farasan region awards a prize to the fisherman who catches the most biomass, in keeping with a long-standing tradition. It is forbidden to sell the catch at the festival. Thus, any fish that appear to be unripe (no running eggs or milt observed) are given away as gifts, eaten by the winners, or thrown away. There are no more live fish in the tank after about 60 min. Despite this heavy harvesting, the annual gathering still occurs. The above-described parrotfish aggregation can only be found in the Red Sea off the Farasan Islands. It is unknown why or how this particular species gathers in this lagoon at the same time each year, but it does. Parrotfish aggregations have never been observed in this way before, and it doesn't appear to be a spawning aggregation. It was recently established that the yearly coral spawning event occurs one day after the aggregation always begins on the day after the full moon (Bouwmeester et al. 2012). A long-running harvest festival and cultural event are based on this annual aggregation, no matter the reason. The Farasan Islands (16°43′44.16″N, 42°4′24.47″E) in the southern Red Sea's Longnose

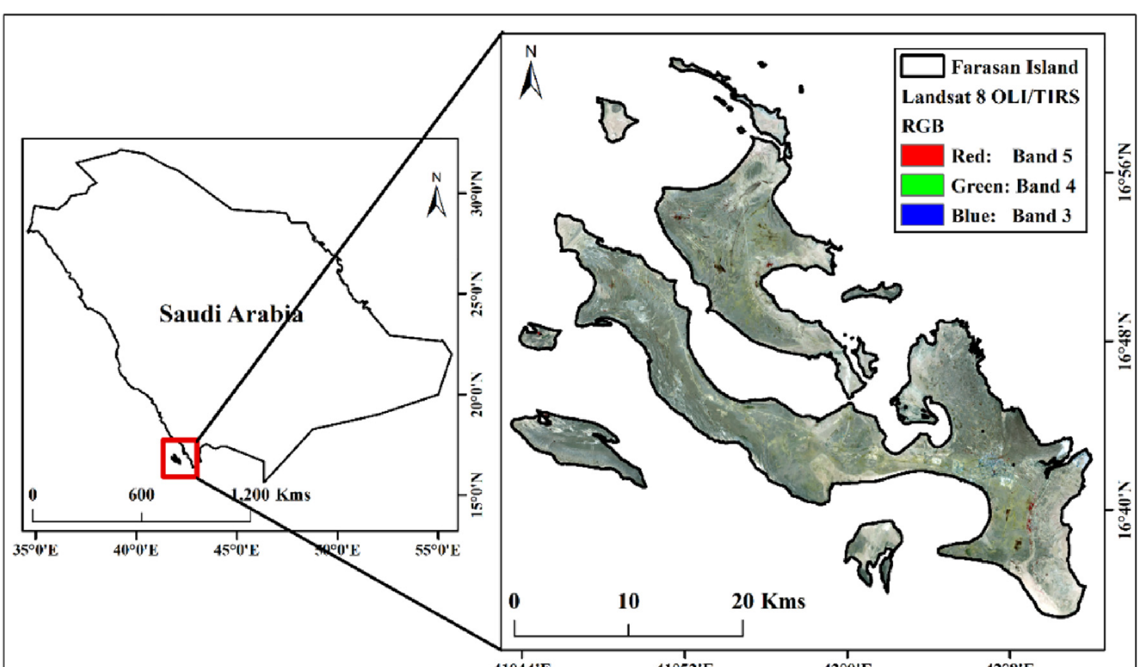

Fig. 1. The location of the studied Farasan Islands, which attracts *Hipposcarus haread*.

Parrotfish (Hipposcarus harid) gather in big schools once a year in the spring (Gladstone 1996). The annual Hareed Festival in Saudi Arabia is celebrated in honour of this gathering, which has been well-known to the citizens of the kingdom for the last two centuries. Some 200–500 individuals (20–30 cm total length) were estimated to be crammed into 3–4 m diameter schools. Each school contained only a single fish in the terminal phase, the only exception being a single pale-colored fish in the early stage. There were no groups of parrotfish seen outside of the lagoon. As part of preparations for this year's Hareed Festival, local fishermen capture 3,000–5,000 parrotfish in the lagoon on the fifth day of the aggregation, when most schools have arrived. People from around the region then converge on the beach per custom. They wait for a signal and then rush into the lagoon, armed with nets. The prince of the Farasan region awards a prize to the fisherman who catches the most biomass, in keeping with a long-standing tradition. It is forbidden to sell the catch at the festival. Thus, any fish that appear to be unripe (no running eggs or milt observed) are given away as gifts, eaten by the winners, or thrown away. There are no more live fish in the tank after about 60 min. Despite this heavy harvesting, the annual gathering still occurs. The above-described parrotfish aggregation can only be found in the Red Sea off the Farasan Islands. It is not known why or how this particular species gathers in this lagoon simultaneously each year, but it does. Parrotfish aggregations have never been observed in this way before, and it doesn't appear to be a spawning aggregation. It was recently established that the yearly coral spawning event occurs one day after the aggregation always begins on the day after the full moon (Bouwmeester et al. 2012). A long-running harvest festival and cultural event are based on this annual aggregation, no matter the reason.

2.2. Environmental study

In the Arabian region, 20 parrotfish species have been discovered, with the majority (17 species) found in or near the Red Sea. Many of these species are indigenous to their location. Scarus arabicus and Scarus zufar are restricted to the Arabian Sea and Oman's southern shore, whereas Scarus persicus is limited to the Arabian Gulf and Oman's coast (Choat et al. 2012). As a result, the taxonomic mix of parrotfishes in the Arabian Gulf, Arabian Sea, and Red Sea is very subregional (Hoey et al. 2016b). The Arabian Gulf has two species (Sc. persicus and Scarus ghobban), the Arabian Sea has two species (Sc. persicus and Scarus ghobban), and the Red Sea has a variety of scraping and excavating species (Hoey et al. 2016b). Despite the similarity in abundance and biomass of parrotfishes between habitats in the Red Sea (Khalil et al. 2017), the absence of reef development and clearly defined reef zones hinder inter-habitat comparisons in the Arabian Sea or Arabian Gulf. From the Red Sea to the Arabian Sea and Arabian Gulf, the species richness and abundance of excavating parrotfishes decrease. Given the region's biogeography, the decline in species richness is to be anticipated, but the lack of digging parrotfishes in the Arabian Sea is notable.Despite the rarity of excavating parrotfishes, Oman's coast has two kinds of excavating parrotfishes. The lack of excavating parrotfishes on Arabian Sea reefs contrasts with the abundance of scraping parrotfishes, implying that their feeding or nutritional ecology may contribute to these disparities. Scratching and digging parrotfishes eat on identical surfaces (dead coral or carbonates covered in EAM), but their bite depth varies. Excavating parrotfishes takes deeper bites and removes more of the underlying substrate with each bite than scraping parrotfishes (Hoey and Bellwood 2008). In this area, the stony reef and the difference in feeding 0habits may have contributed 282 Parrotfish Biology Scraper 30°N 20°N 10°N B. Diggers SAUDI ARA Yemen m Omani SAUDI ARA UAE Oman Yemen 0 250 500 k. Absentee parrotfishes excavating Hard surface feeding has been linked to dental damage in giant Atlantic parrotfishes (Bonaldo et al. 2007). Only two species (Sc. persicus and Sc. ghobban) have been recorded during comprehensive surveys of reefs in the southern Arabian Gulf, with densities of fewer than one individual per 1000 m^2 (Feary et al. 2010). These reefs have low numbers of other herbivorous fishes (i.e., Siganidae, Acanthuridae) (Feary et al. 2010, Burt et al. 2011). Although parrotfish populations have declined globally due to fishing (Taylor et al. 2014), they are not a priority target in the Arabian Gulf (Grandcourt 2012). Temperature shifts can affect tropical species, especially reef fishes, which have evolved in relatively stable thermal conditions and have a lower thermal tolerance than temperate species (Tewksbury et al. 2008). The Arabian Gulf's significant temperature variance (annual temperature range 20 °C) may prevent many tropical species from settling here. The biodiversity of the Arabian Gulf's reef fish is endangered (Burt et al. 2011). Importantly, due to the restriction of feeding during the cooler months, rates of grazing and erosion inside the Arabian Gulf and to a lesser degree, the Arabian Sea may be much lower than these estimates. According to preliminary data for *Sc.persicus* from the northern Arabian Sea, a 6 °C reduction in water temperature (from 29 °C to 23 °C) resulted in a 50–60% decrease in bite rate (Hoey unpublished data). While variations in the nutritional content of food cannot be ruled out, the feeding decrease is consistent with projected temperature-induced changes in metabolic needs.

2.3. Seasonal search for food

In their natural habitat, parrotfishes must choose from various food sources whose availability and nutritional makeup are subject to spatial and temporal variation. Parrotfish strive to meet their daily nutrient requirements to maintain a balanced diet (Rubio et al. 2003). In this case, parrotfish are more likely to seek out food items that contain nutrient deficiencies in the environment and are required in more significant quantities to fulfill life functions (Pretorius et al. 2012). It is exciting to see if coral reef grazers, particularly parrotfishes, respond similarly to their terrestrial counterparts or if they have evolved different mechanisms. Evidence suggests that parrotfishes can choose nutritionally richer resources (Fong et al. 2006).

It is exciting to see if coral reef grazers, particularly parrotfishes, respond similarly to their terrestrial counterparts or if they have evolved different mechanisms. Evidence suggests that parrotfishes can choose nutritionally richer resources (Furman and Heck 2008). There is comparatively more information on the seasonal variations in feeding rate in parrotfishes. Those studies examining parrotfish eating rates over various seasons frequently report (Hatcher 1982) that Summertime feeding rates are higher. Nutritional quality (Burkepile and Hay 2009) and productivity (Russ 2003) correlate positively with parrotfish feeding rate. These variables are more significance in the summer, and the observed increases in feeding rates may be due to Their combined effects with higher temperatures (see below). Other factors that could cause Seasonal variations that influence parrotfish feeding rates include inhibitory peptide concentrations, Ash content, and secondary metabolites (Steinberg 1989, Amade and Lemée 1998). Extreme summer temperatures in the southern Red Sea may prevent parrotfish and other grazing fishes from foraging on shallow reef flats (Afeworki et al. 2013). Amade and Lemée (1998) found olites and ash content significant. As a result, turf biomass in these shallow zones reaches an annual maximum (Ateweberhan et al. 2006). Increased irradiance and temperature in deeper reef zones may facilitate higher productivity, prompting reef grazers and parrotfishes to forage more in deeper zones during summer than in other seasons (Afeworki et al. 2013). Parrotfishes' growth has been studied using age-length data, which reads age (annuli) from sections of hard parts, primarily otoliths (Choat and Robertson 2002). Since the 1970s, researchers have discovered that otoliths from tropical fish form annual alternating growth bands (Fowler 2009). This species' body condition and liver lipid content rise during the spring and peak in the early summer (Afeworki 2014). Van Rooij et al. (1995) studied variation in body condition and growth in *Sp. viride* in Bonaire, the Caribbean, discovered all social categories of *Sp. viride* achieved better body condition, and all individuals (except the largest territory holding males) showed peak growth during the summer. This coincides with the Caribbean's peak season for EAM productivity (Adey and Steneck 1985, Carpenter 1986, Ferrari et al. 2012).

2.3.1. Reproduction of parrotfishes

Several observations indicate that these processes occur in parrotfishes as well. Colin (1978) reported that the number of individuals participating in group spawning in *Sc.iseri* peaks in the summer, implying that more females are in spawning conditions during this season. The percentage of ripe female *Sp.viride* in the Turks and Caicos population varied seasonally and were highest in late winter and early spring (Koltes 1993). Munro et al (1973) found a decreasing proportion of reproductively active females from a winter peak in gonad analyses of several parrotfish species sampled off the Jamaican coast. According to studies that included sampling throughout the year, parrotfish spawn all year, but there appears to be a distinct peak spawning period that varies by region. For example, the Caribbean parrotfish *Sp. viride* spawns every day of the year but with greater frequency during the cooler months (van Rooij et al. 1996). In the Caribbean, the peak recruitment season for parrotfishes and acanthurids is from April to June (Kopp et al. 2012). According to studies that included sampling throughout the year, parrotfish spawn all year, but there appears to be a distinct peak spawning period that varies by region (Table 1). For example, the Caribbean parrotfish *Sp. viride* spawns every day of the year but with greater frequency during the cooler months (van Rooij et al. 1996). The peak recruitment season for parrotfishes and acanthurids in the Caribbean is April-June (Kopp et al. 2012), which supports the observation of a winter spawning maximum. Many reef taxa, including parrotfishes, have been reported to have aIn Kimbe Bay, Papua New Guinea, the spawning season runs from December to March (summer) (Claydon et al. 2014). In contrast to the apparent species- and regional-specific spawning at low-latitude sites, spawning in parrotfishes at higher latitudes appears to be more consistent and limited to the warmer months. *Sc.ferrugineus* in the southern Red Sea demonstrates how environmental conditions shape the temporal pattern of reproductive effort through the resources available to adults rather than their pelagic larvae. The Indian monsoon has a strong influence on this region. *Sc.ferrugineus* prefers on EAM growing on substrates with rich endolithic algae over EAM overtopping crustose corallines because it is more nutritious and gives higher yields per bite. (Afeworki et al. 2011). Because detailed data on feeding, body condition, gonad development, and spawning are not yet available for most parrotfish species, the trade-off between spawning and foraging and its influence on reproduction timing cannot be tested. On the other hand, a winter spawning peak in many parrotfish populations suggests that such a trade-off between feeding and spawning activities may exist.

2.4. Tracking using new technology

During June and July, the habitat use of juvenile southern flounders (Lichthys lethostigma) was studied using acoustic telemetry in a shallow estuarine seascape 2011. Fine-scale movement and habitat use of *P. lethostigma* was investigated with an acoustic positioning system placed in a seascape that varied in habitat type, physicochemical conditions, and bathymetry. Different habitat types were examined with Euclidean distance-based analyses. Further, generalized additive models were used to determine the relative importance of habitat type relative to physicochemical conditions and bathymetry. Tracks of *P.lethostigma* ranged in the distance between 1477 and 8582 m, and speed was 4·2 ± 1·1m min − 1 (mean ± s.e.) for all *P. lethostigma* combined. Depth, slope, and habitat type had the most influence on *P. lethostigma* occurrence, and deep sandy areas with shallow slopes were used most frequently. In addition, depth use by *P.lethostigma* was influenced by tidal cycles, indicating habitat use varies temporally and is dynamic. Finally, temperatures < 30.5 °C were used more than warmer waters within the study area. The results successfully identify movements by juvenile *P.lethostigma*, and indicate that definitions of essential habitats need to account for dynamics in habitat use. (Furey et al., 2013). Also, some elasmobranchs are thought to use shallow temperate estuaries during warmer months because these habitats may provide thermal physiological advantages. However, extensive loss and degradation of southern California bays and estuaries have reduced coastal species' access to estuarine habitats. While restoration of southern California estuaries has increased over the last two decades, little is known about the recovery of ecological function. Top predators are considered important indicators of ecological function restoration in many ecosystems, including estuarine habitats. In this study, abundance surveys and acoustic telemetry were employed to examine how gray smooth-hound sharks (GSH) use the newly restored Full Tidal Basin (FTB) of Bolsa Chica. GSH was most abundant inside the FTB during the spring and summer, and numbers decreased during the winter. Over 83% of all individuals (n = 336) caught were immature juveniles and were most abundant when water temperatures were between 20 and 22 °C. Sharks fitted with acoustic transmitters (n = 22) were continuously detected for 6–153 days (August 2008–December 2009). Forays into coastal waters were uncommon until individuals left for the season. GSH selected warmer habitats within the middle FTB butalso exhibited diel movements along the basin. GSH was most often founciated with mud and

Table 1
Records of monthly spawning in parrotfishes from different coral reef locations of the world.

Species	Location	Spawning time	Peak period	Method
Scarus iseri	Jamaica	Feb-Jun	Winter	Gonad maturation
Scarus taeniopterus	Puerto Rico	Year round	Insufficient data	Spawning
Scarus vetula	Puerto Rico	Jan-Mar, Aug-Dec	Insufficient data	Spawning
Sparisoma aurofrenatum	Jamaica	Year round	Winter - spring	Gonad maturation
Sparisoma cretense	Greece	Jul-Sep	Summer	Gonad maturation
Sparisoma viride	Florida Keys	Year round	Winter	Spawning
Calotomus japonicus	Japan	July-Oct	Summer	Gonad maturation
Chlorurus bleekeri	Kimbe Bay, PNG	Year round	Summer	Spawning
Scarus ferrugineus	Central Red Sea	unknown	Winter	Gonad maturation
Scarus spp.	Zanzibar	Year round	Winter, Oct	Gonad maturation

eelgrass at night, presumably for feeding. Since its restoration, population and behavioral data suggest that the FTB may provide juvenile GSH with a suitable seasonal environment for feeding

Fig. 2. Seasonal Stampede Migratory haread.

Fig. 3. Endemic *Hipposcarus haread*.

and growth. Acoustic telemetry is now a key research tool used to quantify juvenile salmon survival, but transmitter size has limited past studies to larger smolts (>130 mm fork length). New, smaller, higher-frequency transmitters ("tags") allow studies on a larger fraction of the smolt size spectrum (>95 mm); however, detection range and study duration are also reduced, introducing new challenges. The potential cost implications are not trivial. With these new transmitters in mind, we designed, deployed, and tested the performance of a dual-frequency receiver array design in the Discovery Islands region of British Columbia, Canada. We double-tagged 50 juvenile steelheads (Oncorhynchus mykiss) with large 69-kHz tags (VEMCO model V9-1H) and small 180-kHz tags (model V4-1H). The more powerful 69-kHz tags were used to determine the fish presence to estimate the detection efficiency (DE) of the 180-kHz tags. We then compared the standard error of the survival estimate produced from the tracking data using the two tag types, which has important implications for array performance and hypothesis testing in the sea. Perfect detection of the 69-kHz tags allowed us to determine the DE of the 180-kHz tags. Although the 180-kHz tags began to expire during the study, the estimated DE was acceptable at 76% (SE = 9%) when we included single detections. However, 95% confidence intervals on steelhead survival (64%) were 1.5 × larger for the 180-kHz tags (47–85% vs. 51–77% for 69 kHz) because of the reduced DE (Rechisky et al., 2020). Moreover, research on fish movement and habitat use in large tropical rivers is urgently needed to protect fisheries that are a primary source of protein for millions of people. In this pilot study, acoustic telemetry was used to monitor the movements of wild catfishes in a 94.6rkm reach of the Mekong River, which functions as the border between Thailand and Lao People's Democratic Republic (PDR). Twenty fish were tagged, released in May 2006 and monitored through May 2007 with 17 fixed-site acoustic receivers. Ten receivers had detection probabilities ranging from 0.67 to 1.00, and five had detection probabilities of 0.50 or less. Detection probability was not correlated with river width. Eighteen (90%) of the tagged fishes were detected by at least one receiver. Monitoring durations of individual fish ranged from

Fig. 4. Festival migratory *Hipposcarus haread* in the Farasan Islands.

0.1 to 354.4 days. The longest total movement was 88.3rkm, while the longest upstream movement was 52.1rkm. Movement rates ranged from 0.1 to 156.7 rkm/d. This work provided preliminary data on the movement patterns of wild Mekong catfishes. The methods and lessons learned from this study can be used for future positional telemetry research to address management-relevant uncertainties about migration corridors, habitat use, the efficacy of fish reserves, and river development planning (Naughton et al., 2021).

2.5. Seasonal stampede migratory of parrotfish to Farasan Island

Farasan Island is located in the southern parts of the Red Sea, approximately 40 km from Jazan, Saudi Arabia. Geographically, the area is bounded between 16°8″ to 17°10″ N and 41°22″ to 42° 0″ E (Fig. 1). April to October is the summer season, and November to March is the low-hot season on Farasan Island. The annual average temperature of Farasan Island is 30 °C. The relative humidity is 70 to 80% in winter and 65 to 75% in summer. The month with the greatest rain in the area is April. The research region is recognized by its unusual geography in southern Saudi Arabia, where coral reefs multiply annually around these islands. The water is considered warm due to the shallowness of the seawater around the islands. For these reasons, large swarms of migratory haread fisheries flock to the shores of these islands to overtake and relax for a few days from the end of March and the beginning of April of each year. Through the questionnaires distributed to several fishermen in the ports of these islands, it was found that these fish did not carry eggs during this period and that there were no new flocks with them. Referring to these questionnaires, two types of Hipposcarus haread fisheries have been observed. The first is seasonal stampede migratory fish (Fig. 2), and the second is endemic fish, which can be found in the fishermen's nets for every daily fishing trip (Fig. 3). During the arrival of these migratory fish, the Municipality of Farasan Islands organizes the Haread Festival in the presence of the Prince of Jazan Province (Fig. 4).

3. Conclusion

Given the critical roles that parrotfishes play in maintaining coral reef adaptability, a good understanding of how they deal with variations in the sustainability of natural resources will enhance modeling and contexts for future reef states under various disturbances regimes. One strategy for gaining such knowledge is to investigate the variability of parrotfishes regarding seasonal fluctuations in their food sources. Most parrotfishes appear to have restricted dietary versatility. A detailed assessment of several species from the tropical Atlantic and Indo-Pacific regions, representing scraping and excavating feeding modes, show a distinct preference for grazing on EAM growing on substrates infested with boring algae. With the seasonal decline in this preferred food type (generally during the cooler months), food intake is reduced, directly impacting growth rate and body condition. Local environmental conditions that determine resource availability for adults, rather than regional pelagic conditions encountered by their larvae, may influence the timing and intensity of reproductive activity. While seasonal changes in the community composition, productivity, and standing crop of benthic algae on coral reefs have been documented in various settings, little attention has been paid to how such changes propagate through the food web. Seawater temperature anomalies, and severe cyclones are predicted to occur with increasing frequency, so seasonal effects on consumers' resource abundance and feeding activity are likely to amplify. We advocate that there is ample potential for further research on the impact of seasonal shifts in resource abundance and distribution on the feeding ecology and life-history decisions of parrotfishes. Such studies will contribute to a better appreciation of their flexibility in using different algal resources and improve our understanding of annual variations in growth and condition and the timing of reproduction. More generally, a better understanding of the phenology of parrotfishes can help predict their responses to disturbances.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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