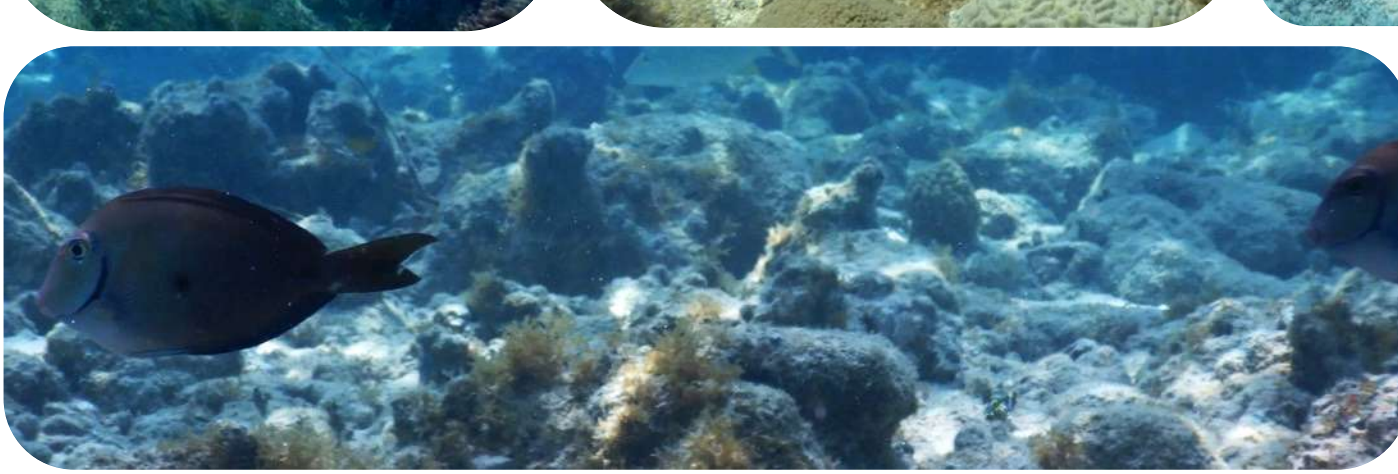
Key Reef Herbivores of Puerto Rico



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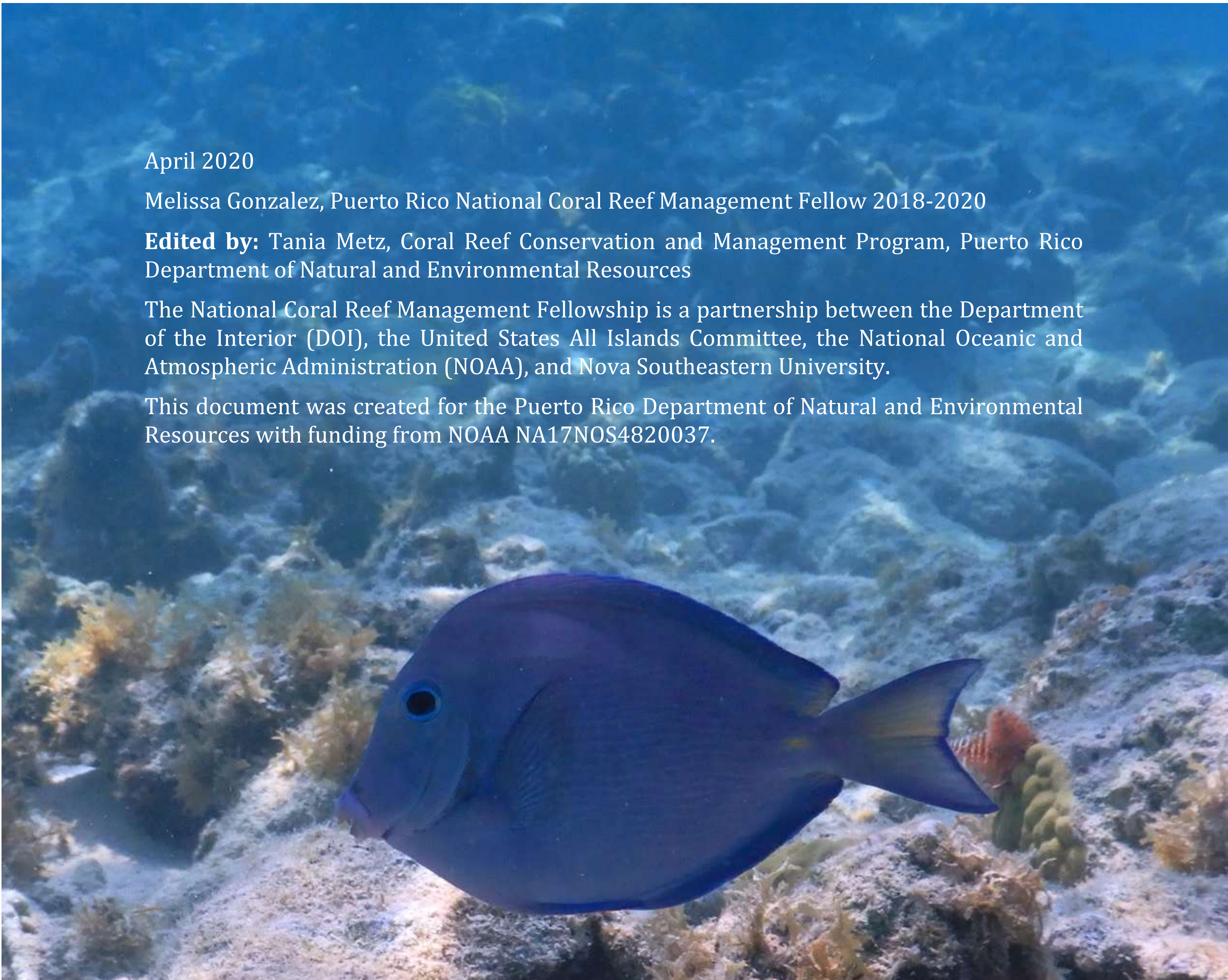

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GLOSSARY

ACRONYMS

A_{50}: Age at 50% maturity

CCA: Crustose Coralline Algae

CFMC: Caribbean Fisheries Management Council

CRCP: Coral Reef Conservation Program

DNER: Department of Natural and Environmental Resources *(DRNA in Spanish)*

FL: Fork Length

ISER: Institute for Socio-Ecological Research, Inc.

IUCN: International Union for Conservation of Nature

L_{50}: The length at which 50% of a population is sexually mature, which is used as an estimate of the size of sexual maturity.

MPA: Marine Protected Area

MRIP: Marine Recreational Information Program

NCRMP: National Coral Reef Monitoring Program (*NOAA*)

NOAA: National Oceanic and Atmospheric Administration

PRCRMP: Puerto Rico Coral Reef Monitoring Program

TD: Test Diameter

TL: Total Length

TNC: The Nature Conservancy

USVI: United States Virgin Islands

DEFINITIONS

Browsers: Herbivores which consume macroalgae and associated epiphytic material [1,2]

Epilithic algae: Algae which grows on the surface of a hard substrate

Endolithic algae: Algae which lives in a hard substrate, such as in coral skeleton or rock

Excavators/Bioeroders: Herbivores which consume both epilithic algal turfs and endolithic algae [1], and may remove hard substrate when feeding, exposing the reef framework and causing bioerosion [2]

Grazers: Herbivores which graze on epilithic algal turfs but do not scrape or excavate substrate [2]

Scrapers: Herbivores which consume epilithic algal turfs [1], macroalgae, sediment, and/or other material close to the reef surface and can leave superficial scrape marks on substrate [2]

Turf algae: Dense, multi-species assemblages of filamentous benthic algae and cyanobacteria that are typically less than 1 cm in height [3]

INTRODUCTION AND METHODS

Climate change, subsequent bleaching and proneness to disease outbreaks, and local stressors including pollution and overfishing continue to threaten coral reefs and reduce their ability to recover and thrive. The Caribbean has seen a significant decrease in live coral cover and increase in macroalgae cover, and Puerto Rico is no exception. Current efforts to increase coral reef resiliency in the Caribbean include direct interventions, such as coral rehabilitation and response to coral reef emergencies, and indirect interventions, such as strengthening key ecological processes that promote coral health and growth.

A phase shift from coral-dominated to macroalgal-dominated reefs in the Caribbean was evident after the 1983 mass mortality of the dominant reef herbivore *Diadema antillarum* [4]. Macroalgae overgrowth can negatively affect coral fecundity, recruitment, growth, and survival [5,6,7] and, in a macroalgae-dominated state, it can be difficult for corals to recover [8]. Increasing reef herbivory is one management approach that aims to reduce algae on coral reefs and thus, under the right circumstances, can reduce the competition between algae and corals, create space for potential coral recruitment, and increase coral cover [9,10].

The Coral Reef Conservation and Management Program of the Department of Natural and Environmental Resources (DNER) views reef herbivory as a key ecological process, and therefore important for the health and resilience of Puerto Rico's coral reef ecosystems. This program uses the 2011-2015 Local Action Strategies for Coral Reef Conservation to guide strategic planning and management actions, whose priorities are listed in the box to the right. In 2017, stakeholders met to review and update these local priorities and determined that, in order to promote sustainable fisheries, it is important to address management gaps in key coral reef associated species and functional groups, including herbivores. In addition, the National Oceanic and Atmospheric Administration (NOAA) includes aspects of reef herbivory in its 2019 Coral Reef Conservation Program (CRCP) Strategic Plan. NOAA's Strategy R1 - *Improve coral recruitment habitat quality* - has two objectives and targets which specifically relate to herbivory:

Main issues prioritized in the 2011-2015 Local Action Strategies:

A. Improve water quality and related reef systems by reducing pollutant inputs from terrestrial sources.

B. Apply immediate protection to commercial, recreational and artisanal coral reef fisheries and related coral ecosystems by employing available management tools to protect and conserve.

C. Reduce those human impacts that are most critical to corals' protection and health.

D. Manage for climate change and diseases emanating from increase in storm frequency and impact, water temperature and air pollution and promote recovery in reefs from previous events.

- Support research and development of effective and efficient herbivore propagation techniques which can be operationalized to replenish these wild populations
    - Target R1.1: By 2022, 80% of restoration projects identify and achieve retention rates of herbivores at key reef sites

- Support and encourage the implementation of herbivore replenishment activities to achieve a reduction of algal growth
  - Target R1.2: By 2024, algal cover is reduced and maintained at predetermined levels at key reef sites.

In response to this priority, the 2018-2020 National Coral Reef Management Fellow was tasked to consolidate the available information to identify Puerto Rico's reef herbivores which likely contribute the most to algal reduction in ways that can benefit coral reef health, and to recommend conservation and management strategies for these key reef herbivores. The information presented in this document was consolidated from a thorough literature review of reef herbivory in the Caribbean, with focus on literature from Puerto Rico and on species which consume algae on coral reefs. Additional information was collected by reviewing local data from Puerto Rico, including data from the Puerto Rico Coral Reef Monitoring Program (PRCRMP), NOAA's 2016 National Coral Reef Monitoring Program (NCRMP), and available commercial and recreational fisheries data. In addition, informal interviews were conducted and one meeting was held to discuss key reef herbivores with key stakeholders on March 21, 2019.

The **objectives** of this document are to:

I. Determine which species are key reef herbivore species (species that remove significant amounts of algae on ideal coral reef habitat) in Puerto Rico.

II. Provide conservation and/or management recommendations for key reef herbivore species.

Determining which herbivores are considered key reef herbivore species will improve our understanding of each species' role in herbivory as a key ecological process and can be used to develop specific strategies to increase and integrate this process into relevant coral rehabilitation efforts.

KEY REEF HERBIVORES IN PUERTO RICO

Each reef herbivore species fills a niche, and may feed on different marine habitats, prefer certain species of algae, and consume them in distinct ways [1,11,12]. Although many reef herbivores affect algal and/or coral community structure to some extent, not all herbivores have an equal effect on benthic communities [1,11]. To determine the key reef herbivores, or the main species with characteristics allowing high effectiveness at removing algae in a way which benefits coral reefs, factors such as algal feeding behavior, habitat, and general abundance in Puerto Rico were informally considered with the available data, meaning a quantitative priority assessment was not conducted and therefore factors were not weighed equally [13]. Note that each reef herbivore species was considered individually in these determinations, however, grazing by many different herbivore species on coral reefs is desired, as this allows for species to complement feeding behaviors and more effectively remove and maintain diverse algal communities [14].

In Puerto Rico, some of the algal consumers on coral reefs include parrotfishes, surgeonfishes, damselfishes, sea urchins, Caribbean king crab (*Maguimithrax spinosissimus*), sea chubs, and sea breams (*Archosargus rhomboidalis*). The majority of available literature on reef herbivory conducted around the Caribbean have focused on sea urchins (specifically *Diadema antillarum*), surgeonfishes, and/or parrotfishes [7,9,10,15,16], and these are even listed as the most important Caribbean reef herbivores for controlling algae [1]. When coral reef stakeholders in Puerto Rico were informally interviewed about important reef herbivores in Puerto Rico, most also mentioned these groups or species within them. Individual species within these groups as well as other key reef herbivore species were investigated, and of these species, a list of ten key reef herbivores was created.

The following sections summarize available information organized by functional group based on feeding behaviors, to explain why each species included should be considered a key reef herbivore in Puerto Rico. For more detailed information on each, please see individual species documents in the appendices. A separate one-pager was produced to summarize the results of this work for educational and outreach purposes.

EXCAVATORS / BIOERODERS

This functional group includes herbivores which consume both epilithic turfs and endolithic algae, which limits macroalgae establishment and clears hard substrate, and these species can also cause bioerosion on reef framework by removing substratum [1,2,17]. Parrotfishes *Sparisoma viride*, *Scarus guacamaia*, and *Scarus coelestinus* are considered excavators/bioeroders. Sea urchins *Diadema antillarum* and *Echinometra viridis* have similar feeding behaviors, and therefore are also included under this functional group [18].

Due to its rarity in Puerto Rico, *Scarus coelestinus* was not included as a key reef herbivore as it likely does not have as large of an effect on algae removal on coral reefs across Puerto Rico in comparison to more abundant herbivore species with similar grazing behaviors.

Diadema antillarum | Long-spined sea urchin

Diadema antillarum is considered one of the most effective reef herbivore species in the Caribbean, as it is an efficient, non-selective algal grazer, including on Puerto Rico's coral reefs [19,20]. It has the ability to facilitate coral reef recovery by creating space for potential coral recruitment on reefs [10,21]. The 1983 mass mortality of more than 93% of the *D. antillarum* population throughout the Caribbean removed much of the top-down grazing pressure on macroalgae, and this event is attributed to the phase change from coral-dominated reefs to macroalgae-dominated reefs [21,22]. Populations of *D. antillarum* in Puerto Rico are reportedly low, yet stable or slightly increasing since immediately after the mortality event, but have not recovered to pre-mortality event levels [19,23,24,25,26], which were documented in Puerto Rico with averages as high as 13.8 individuals/ m^2 [27] and 18 individuals/ m^2 [Vicente & Goenaga 1984 cited in 23]. Mostly adults are seen on Puerto Rico's coral reefs, suggesting limited recruitment and/or survivorship [19,23,26]. Olmeda-Saldaña et al. (*in review*) found that a minimum of five (5) *D. antillarum*/ m^2 are required to remove significant algae and create clean substrate on reefs, whether the rugosity is low or high.

Even with low population abundance, the ability of *D. antillarum* to effectively remove algae from coral reefs is still apparent. Local projects are aiming to increase *D. antillarum* populations by rearing larva *ex situ* and releasing them on coral reefs [20]. In some sites where individuals were released as part of local projects, the 2019 Puerto Rico Coral Reef Monitoring Program (PRCRMP) documented an increase in average densities of *D. antillarum,* such as in La Parguera, sites Media Luna 5 m (13 individuals/ 30 m^2) and Media Luna 10 m (5 individuals/ 30 m^2), which are higher densities than found in the majority of PRCRMP [25]. In comparing results from the PRCRMP in 2015 to 2019, both sites have experienced an increase in average hard coral cover and decrease in average benthic algae cover [25], however, it is uncertain to whether this can be attributed to the increase in *D. antillarum*.

Diadema antillarum was not documented in Puerto Rican commercial nor recreational fisheries. However, 122 individuals were reported in the marine ornamental fishery in Puerto Rico between 2002 and 2005 [28]. Per anecdotal evidence, sea urchins have recently started to be consumed locally.

Echinometra viridis | Reef urchin

Echinometra viridis is a burrowing urchin occurring on coral reefs and rocky substrate [29] in depths up to 40 m [30]. In Panama, *E. viridis* was more abundant on leeward reefs, specifically areas with low sedimentation and high live coral cover [31,32]. Populations of *E. viridis* can be as efficient herbivores as *D. antillarum* populations (Stacey Williams, pers. comm.), since *E. viridis* can consume more macroalgae per day and per weight and is more common in Puerto Rico than *D. antillarum* [32]. High densities of *E. viridis* greatly reduce or remove macroalgae cover, and this species consumes three times more fresh macroalgae than the burrowing sea urchin *E. lucunter* [32]. In one study, an increase of coral cover was documented with high densities of *E. viridis* in the absence of *D. antillarum* [33].

Diadema antillarum and *E. viridis* showed spatial segregation in Puerto Rico and did not have overlap niches [29]. However, after the mass mortality of *D. antillarum, E. viridis* and *E. lucunter* densities significantly increased on Caribbean reef flats [34], which may have allowed *Echinometra* to fill a niche previously filled by *D. antillarum* [18,31]. This may be beneficial by removing algae on reefs where *D. antillarum* no longer appears in high enough densities to control algal abundance. *Echinometra viridis* has not been reported in Puerto Rico fisheries or in the marine ornamental fishery [28].

Sparisoma viride | Stoplight parrotfish

Sparisoma viride is considered a significant contributor to the overall grazing activity on Caribbean reefs [7,35]. In Puerto Rico, it is one of the most abundant parrotfish species, with an average density of 1.2 individuals/ 30 m^2 across 42 sites monitored in the 2018 and 2019 PRCRMP [25,36]. It is also one of the most commercially landed parrotfishes [37], and is the parrotfish with the highest capture in recreational fisheries [38]. High abundance and biomass of *S. viride* on coral reefs in comparison to other parrotfish species in Puerto Rico, as well as its bioeroding/excavating feeding style on turf and macroalgae in high relief areas [1,22], makes it an important reef herbivore for Puerto Rico.

Sparisoma viride is also one of the main parrotfish corallivores [39], however, the majority of its time is spent grazing on algae, with only a small percentage of bites taken on live coral

[40]. It is suspected that the beneficial aspect of its reef herbivory outweighs the negatives on most Caribbean coral reefs [17].

Scarus guacamaia | Rainbow parrotfish

As the largest parrotfish in the Atlantic [41], *Scarus guacamaia* likely consumes more algae per individual than other Atlantic parrotfish species. In addition, this species occurs in inshore, high relief areas (Tom Adam, pers. comm.), where it likely spends its time feeding and contributing to macroalgae removal.

Scarus guacamaia may be more vulnerable to overexploitation. Although no published life history information exists on age, growth, and reproductive biology of *S. guacamaia*, similarly large *Scarus* species for which life history data have been reported exhibit slow growth rates and late onset of reproduction [41]. Sightings of this species have declined in Puerto Rico [22] and it has only been documented twice in the PRCRMP, in 1999 and 2000 [42,43], and twice in southwestern Puerto Rico in the 2016 NCRMP [44]. *Scarus guacamaia* rarely occurs in reported commercial and recreational fisheries landings [38,45]. Although this species is reportedly rare in the U.S. Caribbean [22], anecdotal evidence from fisherfolk report higher abundance of *S. guacamaia*, in comparison to other fishing areas, on the southeastern coast of Puerto Rico. Several *Scarus guacamaia* have been sighted repeatedly over the last four years in Tres Palmas Reserve in western Puerto Rico (Virginia Shervette, *personal communication*). This species is the more common of the three largest parrotfishes in Puerto Rico, *Scarus coelestinus, S. coeruleus, and S. guacamaia*.

Scrapers and Grazers

This proposed functional group includes herbivores which feed close to the reef surface, mainly on epilithic algal turfs [1,2]. Scrapers can leave superficial scrape marks on substrate [2], while grazers tend not to scrape substrate [2]. This group includes parrotfishes *Scarus vetula, S. taeniopterus, S. iseri,* and *S. coeruleus* [1]. In addition, surgeonfishes *Acanthurus tractus* and *A. chirurgus* are included in this group [46]. Scrapers and grazers are important herbivores for their ability to clear substrate from algae and limit macroalgae establishment [1,2].

Scarus coeruleus, the blue parrotfish, is not included as a key reef herbivore species in Puerto Rico, as it appears to be extremely rare and when feeding, tends to target poor recruitment habitat for most corals [1], so likely does not positively affect coral reefs as much as more abundant herbivores who feed on better coral recruitment habitat.

Scarus vetula | Queen parrotfish

Scarus vetula is a medium sized parrotfish, and can reach a maximum size of 61 cm Total Length (TL) [47]. This species occurs on high-relief reefs, which can be important coral recruitment habitat [1]. Few *S. vetula* were documented in the 2018 and 2019 PRCRMP, with an average density of 0.04 individuals/ 30 m^2 [25,36]. In a 2001 to 2007 study in La Parguera, the average density of *S. vetula* was even lower, at 0.02 individuals/ 100 m^2.

Scarus vetula occurs occasionally in Puerto Rico's commercial fisheries (Virginia Shervette, pers. comm.). This species was also reported in Puerto Rico's recreational fisheries between

2000 and 2016 as one of the more abundant parrotfishes landed, however all data available for *S. vetula* from the Marine Recreational Information Program (MRIP) are indicated as imprecise estimates [38].

Scarus taeniopterus | Princess parrotfish

Scarus taeniopterus is a smaller parrotfish, with a maximum size of approximately 33 cm [47], however this species is considered a significant contributor to the overall grazing activity on Caribbean reefs [7]. It has a strong impact on benthic communities undergoing primary succession, by keeping communities in an early successional stage, which facilitates crustose coralline algae (CCA) and coral growth [48]. It had the highest density of parrotfishes documented during the 2018 and 2019 PRCRMP, at 1.78 individuals/ 30 m^2 [25,36]. In La Parguera, *S. taeniopterus* occurred at higher abundance and biomass over colonized hardbottom in the outer shelf zone [22].

S. taeniopterus occurs occasionally in Puerto Rico's commercial fisheries (Virginia Shervette, *personal communication*). This species was also reported between 2000 and 2017 in Puerto Rico's recreational fisheries [38].

Scarus iseri | Striped parrotfish

Scarus iseri is a small parrotfish species, reaching a maximum size of 25.4 cm [47]. It occurs across a variety of habitat types, however, it tends to have a higher abundance over colonized hardbottom with high rugosity [22], and in Belize, *S. iseri* abundance is positively correlated with reef complexity [49]. *Scarus iseri* is one of the more common parrotfish species reported in scientific surveys in Puerto Rico [22], with an average density of 1.23 individuals/ 30 m^2 during the 2018 and 2019 PRCRMP surveys [25,36].

Scarus iseri is extremely rare in Puerto Rico fisheries landings (Virginia Shervette, *personal communication*), however because this species is grouped into the aggregate parrotfish group when reported, the extent of its appearance in commercial landings is unknown. It did appear in commercial landings, but only as one individual measured by port samplers in Puerto Rico's commercial fisheries in 2009 [45]. This species was also reported in 2001 and in 2011 in Puerto Rico's recreational fisheries [38].

Acanthurus tractus | Five-band surgeonfish

Acanthurus tractus is considered a significant contributor to the overall grazing activity on Caribbean reefs [7], consumes large amounts of turf algae in comparison to other herbivores [9], is important for consuming filamentous algae [50], and was documented as a herbivore with one of the highest daily algal consumption rates [35]. It also is suspected to have diverse, flexible, feeding habits [50]. In Belize, *A. tractus* had a strong effect on benthic communities undergoing primary succession, and enhanced the growth of *Porites astreoides* and *Porites porites* [48]. *Acanthurus tractus* had an average density of 0.63 individuals/ 30 m^2 in the 42 PRCRMP sites from 2017 and 2018 [25,36].

Surgeonfish in general are considered "trash fish", or species with little to no market value, in Puerto Rico fisheries [Matos-Caraballo & Sadovy 1990 cited in 51]. Although not reported in commercial fisheries between 2012 and 2017, three *A. tractus* individuals were measured by port samplers in Puerto Rico's commercial fisheries in 2012 [45]. It also appeared in Puerto Rico's ornamental fisheries between 2002 and 2005 [28].

Acanthurus chirurgus | Doctorfish

Acanthurus chirurgus consumes greater amounts of calcified macroalgae in comparison to other herbivorous fishes [12]. Unlike the other two surgeonfish species, it has a thicker walled stomach, which may affect its diet [52]. It is the least common of the three surgeonfish species, with an average density of 0.46 individuals/ 30 m^2 in the 42 PRCRMP sites from 2018 and 2019 [25,36].

Acanthurus chirurgus is grouped together under all surgeonfishes in commercial fisheries in Puerto Rico, however it does not appear in commercial fisheries between 2012 and 2017 [45]. It was listed as one of the species reported in Puerto Rico's marine ornamental fishery [28].

BROWSERS

Browsers consume macroalgae and epiphytic material [1,2], and can potentially aid in reversing macroalgae reef phase shifts by removing overgrowth that other herbivores avoid [53]. However, algae can rapidly regrow when its top is cropped [54], so these species may not be able to regulate overall cover or macroalgae biomass as much as excavators and scrapers, but they can prevent blooms of macroalgae avoided by other herbivores [14].

This group includes parrotfish *Sparisoma chrysopterum, S. rubripinne, and S. aurofrenatum* [1], however, it is important to note that these three are not obligate browsers and can also scrape epilithic algae [17]. It also includes surgeonfish *Acanthurus coeruleus*, and sea chubs *Kyphosus sectatrix* and *K. incisor* [46].

The three parrotfish species in this group were not included as key reef herbivore species. *Sparisoma chrysopterum,* the redtail parrotfish, spends its time in a range of habitats including low relief reefs and seagrasses, and likely does not benefit coral reefs as much as species with similar feeding behaviors that spend their time on better reef recruitment habitat [1]. *Sparisoma aurofrenatum* and *S. rubripinne* are more frequent on colonized hardbottom [22], and are likely important for removing different types of macroalgae on reef habitat. However, in comparison to excavating and scraping grazers, they may not be as effective at removing macroalgae in a way that benefits coral recruitment. Little information on the feeding behaviors of *Kyphosus* spp. in the Caribbean and its importance in reef herbivory is available. Conflicting information from Brazilian reefs suggests that these species could be omnivores [55] or herbivores [46]. However, local research on this species diet could be useful in better understanding its role in herbivory.

Acanthurus coeruleus | Blue tang

Acanthurus coeruleus is considered a significant contributor to the overall grazing activity on Caribbean reefs [7,35], and out of ten Caribbean reef herbivores, was documented as the herbivore with the highest daily algal consumption rate [35]. It was suggested to be classified as a browser based on its feeding behavior [46]. The average density of *A. coeruleus* was 0.63 individuals/ m^2 in the 42 PRCRMP sites from 2017 and 2018 [25,36].

Acanthurus coeruleus is grouped together under surgeonfishes in commercial fisheries and does not appear in commercial fisheries between 2012 and 2017 [45]. However, it was reported in Puerto Rico's marine ornamental fisheries [28] as well as to the Commercial Fisheries Statistics Program, Fisheries Research Laboratory.

CONSERVATION AND MANAGEMENT RECOMMENDATIONS

The following are recommendations to improve efforts in increasing reef herbivory through the conservation and management of key reef herbivores in Puerto Rico.

RESEARCH AND MONITORING

- Track *D. antillarum* in the Puerto Rico marine ornamental fishery and fisheries catch data. Although this species has not been reported in fisheries and is not commonly documented in the marine ornamental fishery in Puerto Rico, this species may go unreported or become a large part of local fisheries. Per anecdotal evidence, sea urchins are harvested locally for consumption and have a high value in Asian markets.
- Research on *Echinometra viridis* as a reef herbivore in Puerto Rico is lacking. Local information about its distribution, population densities, habitat, and feeding behavior can be useful in better understanding local herbivory and optimal densities to avoid high rates of bioerosion on reefs by this species [18].
- Promote species-specific reporting for parrotfishes and surgeonfishes, which will provide data on catch by species. Approximately 10 of 14 parrotfish species in Puerto Rico have occurred in commercial fisheries, and these are combined in one group listed as "Parrotfish" on DNER commercial fishery reporting documents. All three surgeonfishes are also grouped together, and although thought to be of little market value in Puerto Rico fisheries [Matos-Caraballo & Sadovy 1990 cited in 51], they are of high value in the USVI and may eventually become a larger part of local fisheries as other fisheries are reduced.
- Track parrotfishes and surgeonfishes in both commercial fisheries and recreational fisheries and utilize this information to monitor how fisheries are affecting these populations, through information such as annual catch compared to maximum sustainable yield, and changes in average species size through time.
- Fisheries-independent sampling is needed for all of the parrotfish species caught as part of commercial and recreational landings. Dr. Virginia Shervette of the University of South Carolina is investigating life history (age, growth, and reproductive biology) of parrotfishes across the U.S. Caribbean using mainly fisheries-dependent samples, and strongly recommends collecting this data.
- Collect data on parrotfish sizes and phases in commercial and recreational fisheries as well as Puerto Rico monitoring programs such as NCRMP and Reef Check, as this can be a good indicator of population status and changes through time, as size tends to decrease with increasing fishing pressure and in some parrotfish species, the percent of terminal phase individuals in a population [56].

- Spawning aggregation location, season, aggregation size, if aggregations are targeted for fisheries, and other important information for those key reef herbivore fish which form spawning aggregations, including *Scarus iseri, Acanthurus coeruleus,* and *A. tractus* [57].
- A better understanding of the marine connectivity and larval dispersion between other areas in the Caribbean and Puerto Rico, as parrotfishes from surrounding islands, such as St. Thomas, could be providing recruits to Puerto Rico [58]. Dr. Virginia Shervette is currently investigating the population genomics of stoplight, redtail, princess, and redband parrotfish species from across the U.S. Caribbean and evaluating the potential contributions of a few Marine Protected Areas (MPAs) as source populations. She strongly recommends similar studies for the other parrotfish species.
- Promote online platforms for citizen scientists, such as iNaturalist, to report observations with photos of parrotfishes in Puerto Rico as another way to collect information on populations.

Education and Outreach

- Educate law enforcement, port surveyors, fisherman, and other stakeholders on the different species of parrotfishes and surgeonfishes, including juvenile, initial, and terminal phases, to improve reporting accuracy.
- Expand educational efforts towards resource users, managers, and the public about the importance of reef herbivores on coral reef ecosystems and to responsibly consume parrotfishes by avoiding those species that are threatened by overfishing. Organizations that have implemented such educational efforts include The Nature Conservancy (TNC) and the Institute for Socio-Ecological Research, Inc. (ISER).

Population Management

- Continue and expand projects to augment *D. antillarum* populations. Low fertilization rates [59], recruitment rates and/or survivorship may be contributing to limited population growth of *D. antillarum* [23]. Efforts to increase population sizes by rearing and then reintroducing individuals on suitable coral reefs in Puerto Rico appear to be successful in increasing populations of *D. antillarum* [20,25], and this increase can help to improve fertilization success, which is necessary to obtain reproductively viable [59]. When increasing populations, aim for a density that will reduce algae cover and increase clean substrate to benefit coral reefs, such as the suggested 5 *D. antillarum*/ m^2 (Olmeda-Saldaña et al., in review)
- *Echinometra viridis* likely needs high population densities in order to control algae [32], so augmenting their populations could also prove beneficial. Dr. Stacey Williams has suggested complementing *D. antillarum* reintroduction efforts with *Echinometra* reintroductions, which could help to increase herbivory on different areas of the reef and on different algal species. *Echinometra* larvae can be captured and raised similarly to *D.*

antillarum, so these species can be reared in tandem and be a cost-efficient addition to ongoing projects.

- Place minimum size limits on the species of parrotfish that are suspected to be overfished. This is a recommendation proposed in a Regulatory Amendment by the Caribbean Fishery Management Council (CFMC) and National Marine Fisheries Service [60]. However, it is suggested to treat each parrotfish species separately and set different minimum size limits, unless those species are difficult to differentiate from one another, such as juvenile or initial phases of *Scarus taeniopterus* and *S. iseri*. When setting a minimum size limit, size at sexual maturity plus a buffer zone should be considered to allow individuals a chance at reproduction before they are removed from a population. These should be based on the most relevant (local) and recent information on each species' size at sexual maturity. Dr. Shervette is researching size at sexual maturity and size at sexual transition for seven parrotfishes in Puerto Rico. Once finished, her data could be used to inform management decisions for those parrotfishes.
- When applicable, harmonize Federal regulations with Commonwealth regulations for parrotfishes to avoid confusion and strengthen law enforcement, as it is difficult to determine if fishes were caught within Federal or territorial waters.

  Current laws pertaining to parrotfishes only apply in U.S. Federal Waters in the Exclusive Economic Zones (EEZ) of Puerto Rico and the USVI [47]. The capture and possession of the three largest parrotfish, *Scarus coelestinus, Scarus coeruleus,* and *Scarus guacamaia* is prohibited. In recreational fisheries within Federal waters, there is a 2 parrotfish per person per day or 6 parrotfish per vessel per day regulation, which applies to the following species: *Sparisoma aurofrenatum, Scarus taeniopterus, Scarus vetula, Scarus iseri, Sparisoma chrysopterum, Sparisoma viride,* and *Sparisoma rubripinne* [47].

OTHER

- Maximize herbivore species richness when managing reef herbivory, to promote complementary feeding behaviors and diets [14], which can remove various types of algae instead of only the specific species of algae consumed by one herbivore species [14].
- Concentrate on large increases of herbivore populations and/or biomass, as this may be necessary for coral recovery in order to overcome population bottlenecks on degraded reefs [61].

CONCLUSION

Coral reef herbivores are important due to their feeding behavior, habitat, populations, and other characteristics that make them efficient at removing algae from reefs around Puerto Rico. Key reef herbivores for Puerto Rico are sea urchins *Diadema antillarum* and *Echinometra viridis;* parrotfishes *Sparisoma viride, Scarus guacamaia, S. vetula, S. taeniopterus, S. iseri;* and surgeonfishes *Acanthurus tractus, A. chirurgus,* and *A. coeruleus.*

The intent of focusing on reef herbivory is to promote an increase of a key ecological process that is considered vital for coral reef health and resilience. Large increases of algal grazing are likely necessary for coral recovery in order to overcome population bottlenecks on degraded reefs [61], so key reef herbivore species populations and/or biomass may need to be increased for a beneficial effect. In addition, as each herbivore plays its own role on the reef in terms of grazing behaviors, diet, and habitat, it is recommended that herbivore species richness be considered when managing for an increase of reef herbivory, rather than only a few species, to allow the beneficial effect of complementary feeding behaviors and diets [14].

It is important to recognize that herbivores which are not listed as “key reef herbivore” may still be important contributors to algal removal on the reef, however factors such as low abundance or grazing habitat may be limiting their contribution. These factors have a potential to change, as well as our understanding of Puerto Rico’s reef herbivores with new research, and therefore species will likely be added and/or removed from this list.

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One-pager – Herbívoros claves de los arrecifes de coral en Puerto Rico

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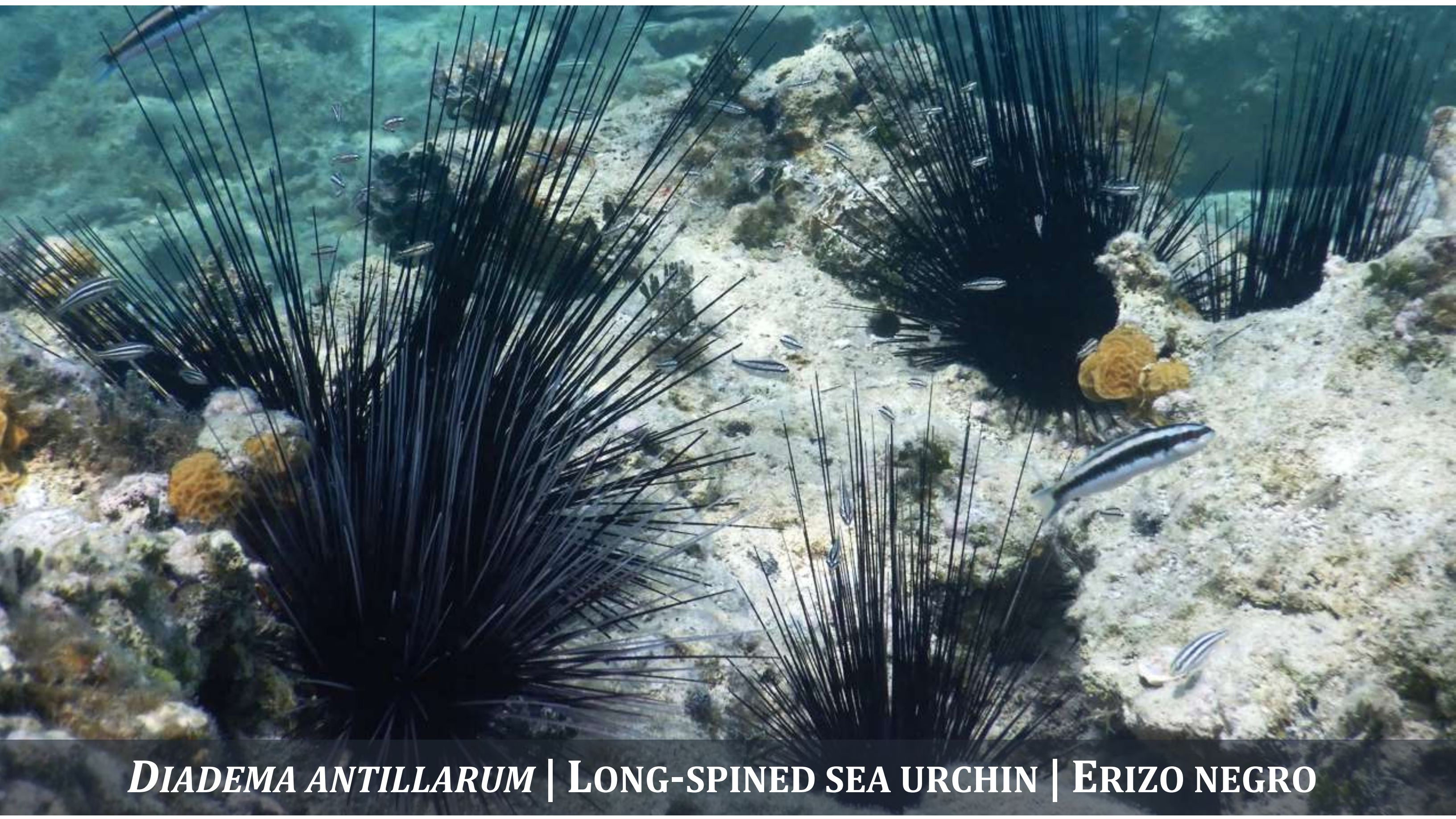
APPENDIX

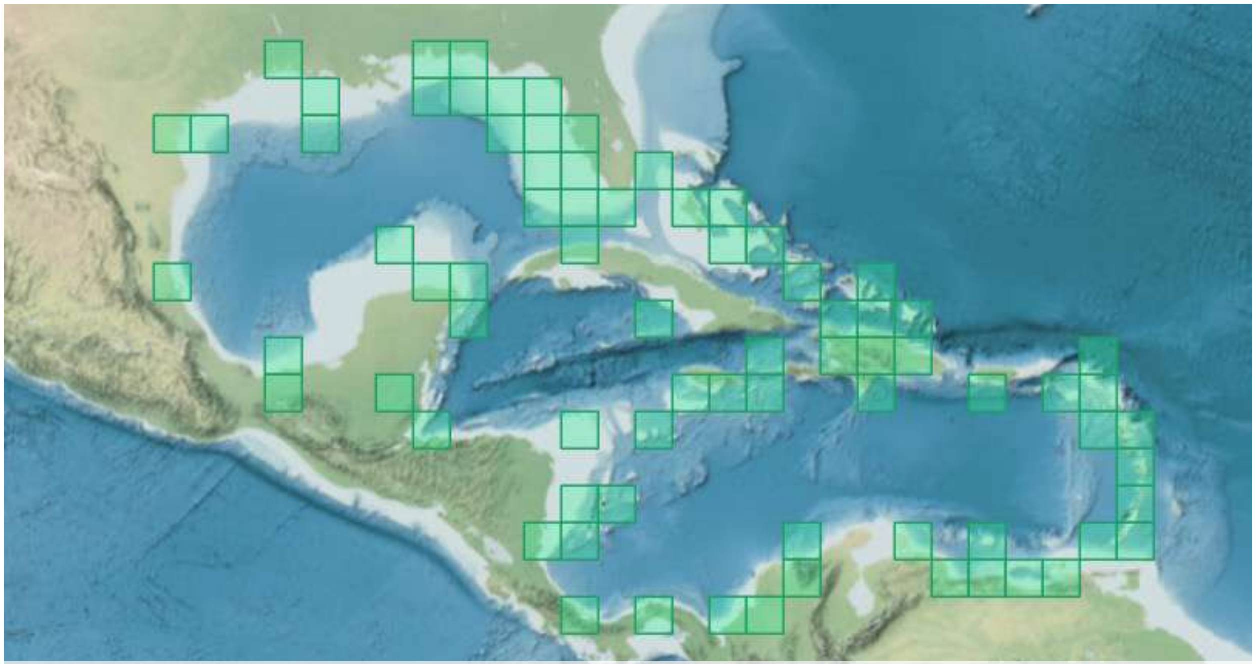
Individual documents with relevant information for each key reef herbivore species can be found below.



DIADEMA ANTILLARUM | LONG-SPINED SEA URCHIN | ERIZO NEGRO

RANGE

- Gulf of Mexico and Caribbean Sea [62]



Documented distribution of *D. antillarum* from the World Register of Marine Species

HABITAT

- Occurs on coral reefs, rocky bottom, seagrass beds, and mangroves [22,63]
- Has higher abundances in shallow areas, in areas with low wave energy, but can also occur in depths up to 400 m [63, 64]

DIET

- Non-selective grazer [65] and effective at controlling macroalgae and facilitating coral dominance on coral reefs in the Caribbean [66]
- Especially efficient in grazing turf algae and *Dictyota* spp. [20; Olmeda-Saldaña et al., in review]
- The only herbivore observed to consume *Ramicrusta* species in Puerto Rico, both *in situ* and *ex situ* [67,68]
- In order to limit algal growth effectively, the critical population size of *D. antillarum* seems to be greater than 2 individuals/ m^2 [Steiner & Williams 2006; Myhre & Acevedo-Gutiérrez 2007; Hernández et al. 2008 cited in 23]
- One *D. antillarum*/ m^2 is not enough to control algal cover and a minimum of 5 *D. antillarum*/ m^2 are required to remove significant algae and create clean substrate on reefs, whether the rugosity is low or high (Olmeda-Saldaña et al., in review)

LIFE HISTORY TRAITS

Size classes [Ebert 1983 and Lessios et al. 1984 cited in 23]

- Juveniles – individuals < 2.0 cm Test Diameter (TD)
- Early adults – individuals 2.0 – 4.0 cm TD
- Adults – individuals > 4.0 cm TD

Reproduction

- Broadcast spawners [59]
- Spawning was documented to be most common in the afternoon, and most spawning activity occurred on days with a full moon [69]
- In the Florida Keys, fertilization success dropped from greater than 96% to 3% after the 1983 and 1991 mass mortality events, and continues to remain low [59]

Size at Sexual Maturity

- Between 2.5 and 3.0 cm TD [69]

BEHAVIOR

- Can be irregular in distribution, as they sometimes cluster together in large numbers [22]
- Nocturnal and highly sensitive to light, and uses shadows to detect predators [70]

POPULATION TENDENCIES*

*Note that because *D. antillarum* are patchy in their distribution and authors may use different methodologies, population estimates may not always accurately depict *D. antillarum* populations [11]

Caribbean

A mass mortality event began in 1983 when a pathogen infected *D. antillarum* in Panama and spread through populations across the tropical western Atlantic [71]. Documented localities in the Caribbean have shown a large decrease of *D. antillarum* densities after the event. Before the mortality event, average densities were high, such as in Barbados where an average of 17.3 individuals/ m^2 was documented [Hunte et al. 1986 cited in 24], but these populations plummeted when more than 90% of the population was affected by the event [71].

Puerto Rico

Pre-mortality densities of up to 18 individuals/ m^2 of *D. antillarum* were documented in Puerto Rico [Vicente and Goenaga 1984 cited in 23]. Additional sources documented the following densities before the mortality event: San Juan - 13.8 ind/ m^2 [27], Jobos Bay - 2.6 ind/ m^2 [Rivera and Vicente 1976 cited in 24], Turrumote - 12.7 ind/ m^2 [Craft 1975 cited in 24], and Guayanilla - 3.0 ind/ m^2 [Vicente and Goenaga 1984 cited in 24]. Densities in Puerto Rico after the mass mortality event are included in subsequent sections. Studies after the event suggest a slight increase in populations in some areas since right after the event, including in Puerto Rico [23,24].

La Parguera

In 2001, *D. antillarum* were assessed in La Parguera and found to have average densities ranging from 0.83 ind/ m^2 in Laurel Reef to 1.55 ind/ m^2 in Caracoles Reef [24]. A follow up study in 2013 found average densities ranging from 0.35 ind/ m^2 in seagrass-cover mounds to 1.81 ind/ m^2 in Laurel Reef [26]. In the 2013 study, higher densities of *D. antillarum* were documented in shallower areas with higher rugosity [26]. *D. antillarum* populations do not seem to have increased between 2001 and 2013, and most individuals in both studies were adults measuring 5 to 9 cm TD, suggesting limited recruitment and/or survivorship [26].

In 2006 and 2007, a different study documented 192 individuals total in only 12 out of 314 sites surveyed [22]. Most individuals were clustered in large numbers and documented on hardbottom, less on softbottom, and none in mangroves [22]. In contrast, higher abundances of *D. antillarum* have been spotted on mangroves in comparison to reefs in La Parguera (Manuel Olmeda, pers. comm.).

PRCRMP

Between 1999 and 2018, *D. antillarum* were documented in approximately 19% of sites in the PRCRMP [72]. Average densities in these sites were low but ranged from 0.2 ind/ 30 m^2 to 10.2 ind/ 30 m^2 (Cibuco, Vega Baja, 2018).

In the 2019 PRCRMP, *D. antillarum* was present in just 3 of 21 monitored sites [25]. The species was documented in Gallardo Reef, Cabo Rojo (average 0.4 ind/ 30 m^2), Media Luna 10 m, La Parguera (average 5 ind/ 30 m^2), and Media Luna 5 m, La Parguera (average 13 ind/ 30 m^2). In 2016, 152 *D. antillarum* young adults were released in Media Luna, La Parguera, which likely contributed to the higher densities documented in this area afterward [20].

NCRMP

In 2016, the highest density of *D. antillarum* was 0.12 individuals/ m^2 found on shallow hardbottom habitat [44].

Recreational Catch and Commercial Landings

D. antillarum is not documented in recreational or commercial catch in Puerto Rico, however, sea urchins are harvested locally for consumption (Daniel Matos-Caraballo, *pers. comm.*). Between 2002 and 2005, *D. antillarum* made up 0.17% of all reported marine species in the marine ornamental fisheries of Puerto Rico, where 122 individual *D. antillarum* were documented and sold for approximately $1.00 each [28].

THREATS

- The mass mortality in 1983-1984 throughout the Caribbean greatly reduced population sizes. The first diseased urchins reported in Puerto Rico were near Laurel Reef in La Parguera in January 1984 [Vicente and Goenaga 1984 cited in 22].
- In the Florida Keys, fertilization success of *D. antillarum* significantly decreased right after the mass mortality events in 1983 and again after another localized disease outbreak in 1991 [59]. Due to spatial isolation and low populations, fertilization success is likely low in Puerto Rico as well.
- Recruitment rates are likely low since juveniles were rare or absent from *D. antillarum* populations and have not significantly increased [23,26]
- *D. antillarum* could be negatively affected by *Acropora cervicornis* dominance, which is thought to be because of the association between *A. cervicornis* and the threespot damselfish, an effective competitor of *D. antillarum* [66]

LOCAL PROJECTS AND PROTECTION

Projects

To increase herbivory on coral reefs, Dr. Williams has been collecting *D. antillarum* larvae, rearing them *ex situ,* and releasing sub-adults onto coral reefs, including on the backreef of Media Luna, La Parguera in 2016 [20] and on the backreefs of Cayo Diablo and Los Lobos, off of Fajardo, in 2018 [73]. These and related projects are expected to continue and expand to increase populations and therefore reef herbivory on additional reefs in Puerto Rico.

Manuel F. Olmeda-Saldaña, graduate student from the Department of Marine Sciences at the University of Puerto Rico Mayagüez, is completing his thesis in La Parguera, focused on determining ideal population densities of *D. antillarum* for optimal reef herbivory on coral reefs.

Legal Protection Status

On October 6, 2014, Administrative Order Number 2014-09 was signed by the DNER secretary to establish measures to protect and ban the capture of sea cucumbers (*Holothuria* spp.) and sea urchins (Echinoidea). This temporarily banned the fishing, possession, transport, sale, buying, or export of these species, for a year after it was signed.

Currently, *Diadema antillarum* has no specific protection status in Puerto Rican waters. However, damaging or removing any coral or associated marine organisms in Puerto Rican waters is prohibited under Law 147 of 1999.

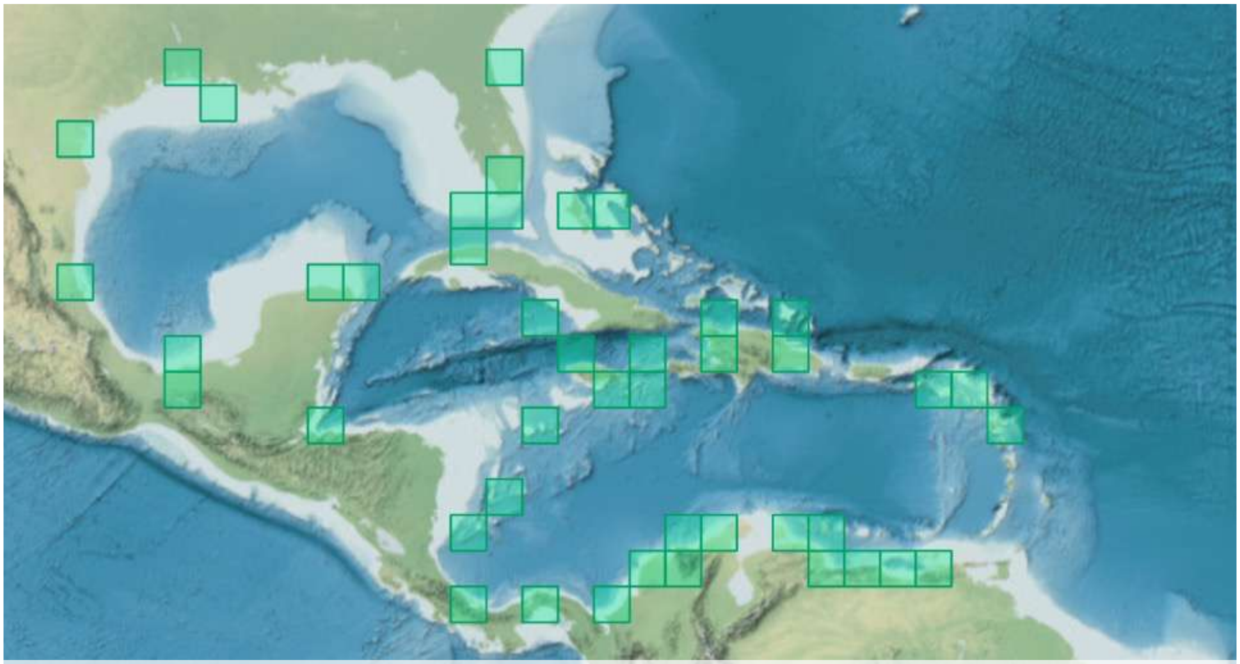
Relevant Knowledge Gaps

- Identification of the pathogen which caused the mass mortality of *D. antillarum* in 1983-1984
- Limitations to fertilization, recruitment, and survivorship which likely are preventing population growth
- Updated data on densities and locations of *D. antillarum* that can give a better representation of the status of this species around the archipelago
- The extent of harvest of *D. antillarum* in Puerto Rico

ECHINOMETRA VIRIDIS | REEF URCHIN | ERIZO DE ARRECIFE

RANGE

- Florida to Venezuela, in the Gulf of Mexico and the Caribbean Sea [74]



Documented distribution of *E. viridis* from the World Register of Marine Species

HABITAT

- Found on coral reefs and rocky substrate [29] in up to 40 m depths [30]
- Appears to be limited to leeward reefs with low sedimentation and high live coral cover, as was seen in Panama [32]

DIET

- Consumes algae, seagrasses, and calcium carbonate, and occasionally sponges and corals [75,18,76]
- Can consume more fresh macroalgae by day and by weight then *Diadema antillarum* or *Echinometra lucunter* [32]
- Reported to prefer early-successional turf algae, but is a generalist herbivore when food is scarce [32]
- Avoids late-successional and fleshy macroalgae (*Lobophora variegata* and *Halimeda opuntia*) [32]

LIFE HISTORY TRAITS

- Mean sizes in La Parguera are between 2 and 2.5 cm TD [18]

Reproduction

- Broadcast spawners [77]
- Spawning season is from September to November in Puerto Rico [Cameron 1986 cited in 78]
- Larval period is estimated to be 30 days [Cameron 1986 and Emlet et al. 1987 cited in 78]

Size at Sexual Maturity

- Approximately 1.5 cm TD for both sexes [75]

BEHAVIOR

- Bioerosion rates of calcium carbonate are highest in shallow waters (1-3 m depth), and an average bioerosion rate per individual (size 2 – 2.5 cm TD) of 0.181 ± 0.104 g/day was documented in La Parguera [18]
- Spatially segregated from *Diadema antillarum* and *Echinometra lucunter,* suggesting that each species have distinct niches on coral reef systems [32]
- Can have a large effect on coral reef communities in the Caribbean [32,18]
- Grazing tends to be very patchy [32,33]
- Can greatly reduce or completely remove macroalgae with high densities [32]
- Its consumption rate of fresh macroalgae per day is three times higher than *E. lucunter* [32]
- Can promote the establishment of new scleractinian coral species [33]

POPULATION TENDENCIES

Caribbean

Right after the *Diadema antillarum* mass mortality event in 1983, densities of *Echinometra viridis* and *E. lucunter* increased [34]. *E. viridis* is now one of the most abundant sea urchins in the Caribbean [32,31].

Puerto Rico

La Parguera

Densities of 0.8 to 62.6 ind/ m^2 were documented in La Parguera, with higher densities documented in shallower areas, 1-3 m depths [18].

PRCRMP

In 2018, three individuals were documented in two sites, and no individuals were documented in 2019 [79,25].

NCRMP

The NCRMP does not document all macroinvertebrates, and no data for *E. viridis* is available.

Recreational Catch and Commercial Landings

E. viridis is not documented in recreational or commercial catch in Puerto Rico, and it was not reported in marine ornamental fisheries documents in Puerto Rico.

THREATS

Various sea urchin mass mortality events have occurred in Puerto Rico, including three occasions in 1965 from extreme temperatures [Glynn 1968 cited in 77], the 1983 mass mortality of *D. antillarum* due to a pathogen, unexplained 1984-1985 die off of *Astropyra magnifica* and 1985 die off of *Eucidaris tribuloides* [Bunkley-Williams et al. 1986 cited in 77], and a 1995 die off of *Tripneustes ventricosus* [Williams et al. 1991 cited in 77].

LOCAL PROJECTS AND PROTECTION

Projects

No current projects involving *E. viridis* in Puerto Rico were identified

Legal Protection Status

On October 6, 2014, Administrative Order Number 2014-09 was signed by the DNER Secretary to establish measures to protect and ban the capture of sea cucumbers (*Holothuria* spp.) and sea urchins (Echinoidea). This temporarily banned the fishing, possession, transport, sale, buying, or export of these species, for a year after it was signed.

Echinometra viridis has no specific protection status in Puerto Rican waters. However, damaging or removing any coral or associated marine organisms in Puerto Rican waters is prohibited under Law 147 of 1999.

RELEVANT KNOWLEDGE GAPS

- Updated data on densities and locations that can give a good representation of the status of *E. viridis* around Puerto Rico
- Localized information on the amount of algae consumption on reefs in comparison to other herbivores
- Ideal population densities to prevent coral reef degradation [18]

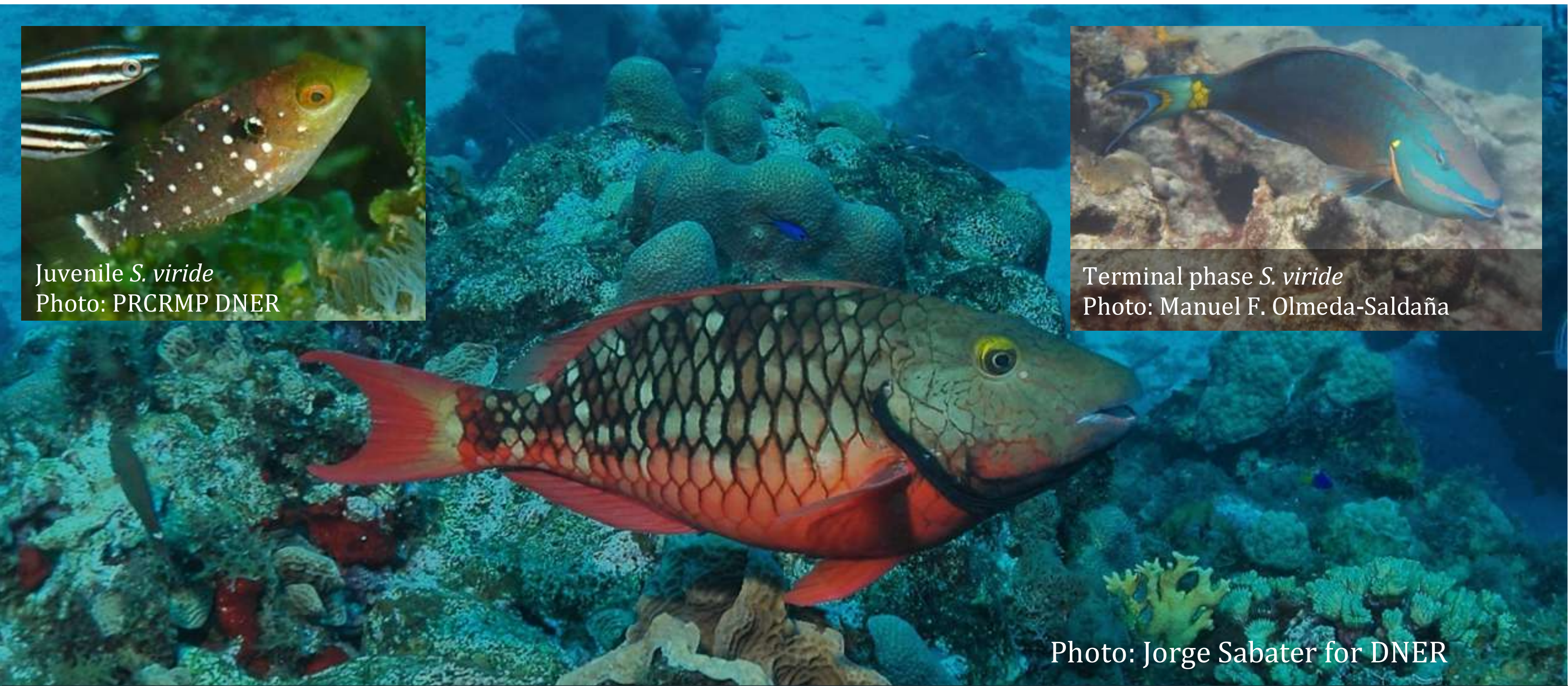


Photo: Jorge Sabater for DNER

Juvenile *S. viride*
Photo: PRCRMP DNER

Terminal phase *S. viride*
Photo: Manuel F. Olmeda-Saldaña

Sparisoma viride | Stoplight parrotfish | Loro verde

Range

Geographic range of *S. viride* from the IUCN Red List

Habitat

- Associated with coral reefs and seagrasses [80], but juveniles and adults occur at higher densities over colonized hardbottom with high rugosity, including patch reefs, colonized pavement with or without sand channels, and fringing reefs [22]
- Occur in depths up to 50 m [80]

Diet

- Classified as an excavating/bioeroding grazer [1]

- Consumes a variety of algae, including crustose coralline algae, and preferred feeding surfaces were documented to be predominantly turf algae [11], then *Dictyota* spp. [40]
- Is one of the main parrotfish corallivores [39], however >95% of bites by *S. viride* are documented to be from algae [7,40]

LIFE HISTORY TRAITS

- Maximum recorded size is 64 cm TL [22]
- Rated as having medium resilience, as the minimum population doubling time is from 1.4-4.4 years [Froese et al. 2017 cited in 81]
- Maximum age documented is 14 years (Virginia Shervette, pers. comm.)
- In the Caribbean, all fishes in the genus *Sparisoma* start out life as female [Choat and Robertson 1995 cited in 56]

Reproduction

- Protogynous hermaphrodite [80]
- Stoplight parrotfish populations in Puerto Rico and the U.S. Virgin Islands spawn year-round [82]
- Female stoplight parrotfish can spawn every 2-6 days [82]

Size at Sexual Maturity and Sexual Transition

- Length at 50% maturity (L_{50}) ranged from 16 cm FL for *S. viride* from St. Croix, USVI to 19 cm FL for *S. viride* from St. Thomas, USVI. In Puerto Rico, the L_{50} for *S. viride* was 17 cm fork length (FL) [82]
- Within their first year, the majority of *S. viride* reach sexual maturity [82]
- In Puerto Rico, 50% of female *S. viride* transitioned to males at 26 cm FL [82]

BEHAVIOR

- Solitary or appears in small groups [80]
- Single terminal males can hold a territory with several females, where daily spawning can occur [83]
- Active during the day and spend about 70 to 90% of the time foraging [Hanley 1984 and van Rooij & Bruggemann *pers. obs.* cited in 40]
- Adult *S. viride* prefer grazing on convex surfaces over flats surfaces [11]
- Tend to feed on substrate in high relief areas [1]
- Takes slow bites in comparison to queen parrotfish (*Scarus vetula*), and this generally leaves grazing scars [11]
- As a corallivore, *S. viride* can leave narrow, elongate scars and lesions on *Colpophyllia, Orbicella, Acropora, Porites* and *Millepora,* and can kill entire colonies when feeding in groups [84]

Population Tendencies

Caribbean

- One of the most abundant parrotfishes [17,85] and common throughout its distribution [80]
- Listed as "Least Concern" by the IUCN Red List [80]

Puerto Rico

La Parguera

- Between 2001 and 2007, *S. viride* had a mean abundance of 1.1 ± 0.08 individuals in 100 m^2 and mean biomass of 196.4 ± 19.8 g/ 100 m^2 [22]
- In this study, the lowest mean biomass was documented in 2001, while the highest mean biomass was documented in 2007 [22]
- The highest abundances occurred over patch reef habitat, but *S. viride* was also occurred over colonized bedrock, linear reef, colonized pavement with or without sand channels [22]
- The majority of individuals observed between 2001 and 2007 were 15 cm Total Length (TL) or smaller, and the most common sizes were juveniles <5 cm TL [22]

PRCRMP

There were 42 sites total monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *S. viride* density of 1.2 individuals/ 30 m^2 [85,25]. Approximately 35% of *S. viride* individuals documented during this period were of recruitment size class (1-5 cm TL), and the next highest percentage at 15% were 26-30 cm TL. No individuals above 40 cm TL were documented.

NCRMP

A mean density of 1.69 individuals/ 177 m^2 was documented for *S. viride* in the 2016 NCRMP [44]. The majority of *S. viride* were in size class 15-20 cm TL, followed by 5-10 cm TL, 10-15 cm TL, and <5 cm TL [44].

Recreational Catch and Commercial Landings

Commercial Fisheries

S. viride is one of the most commercially fished parrotfish in Puerto Rico [37]. From 1988 to 1992, *S. viride* and *S. chrysopterum* were the most commonly reported parrotfish species landed in Puerto Rico [86]. For all gear types, commercial fishers caught larger individuals in 1988 (28 cm FL) than in 1992 (26 cm FL) for *S. viride* [86].

Recreational Fisheries

S. viride is recreationally fished and based on MRIP data, appears to be the most common parrotfish caught in recreational fisheries [38].

THREATS

- Rated to have a low to moderate intrinsic vulnerability to fishing based on its life history and ecological characteristics [87 cited in 88]
- Overfishing, which can also skew the sex ratio [56]
- Severe population declines of *S. viride* in reefs close to densely populated areas around Haiti and Jamaica [Hawkins and Roberts 2004 cited in 80]
- Predation by lionfish [17]

LOCAL PROJECTS AND PROTECTION

Projects

S. viride, Sparisoma chrysopterum, Sparisoma rubripinne, Scarus guacamaia, and S. vetula are covered in the DNER project *Description and Analysis of the Parrotfish Market Fishery's Supply Chain*.

Dr. Virginia Shervette of the University of South Carolina is investigating age, growth, and reproductive biology (including size at sexual maturity and size at sexual transition), for seven parrotfish species (*Sparisoma viride, S. chrysopterum, S. aurofrenatum, S. rubripinne, Scarus vetula, S. taeniopterus, S. iseri*) in Puerto Rico, St. Thomas, and St. Croix.

Legal Protection Status

For recreational fisheries within U.S. Federal Waters in the Exclusive Economic Zone (EEZ) of Puerto Rico, there is a 2 parrotfish per person per day or 6 parrotfish per vessel per day regulation, which applies to the following species: *Sparisoma aurofrenatum, Scarus taeniopterus, Scarus vetula, Scarus iseri, Sparisoma chrysopterum, Sparisoma viride,* and *Sparisoma rubripinne* [47].

Proposed

The DNER's Regulation Number 6766 of 2004, created to regulate vulnerable and endangered species in the Commonwealth of Puerto Rico, was proposed to be updated in 2016 [89]. The new proposed Appendix I. List of Vulnerable and Endangered Species, included *Sparisoma viride* under the category Endangered, defined as a species with a high risk of extinction in the wild in the medium term, because of overfishing.

In 2013, the Regulatory Amendment 4 to the Fishery Management Plan for the Reef Fish Fishery of Puerto Rico and the USVI listed alternatives for minimum size limits for commercial and recreational parrotfish fisheries, which includes *S. viride* [60]. However, the preferred alternatives pertain only to St. Croix, while alternatives pertaining to Puerto Rico are listed but are not preferred.

Relevant Knowledge Gaps

- Fisheries-independent monitoring surveys which measure the size at sexual maturity and sexual transition in Puerto Rico
- A comparison of populations and their size and age structure over time, representative of Puerto Rico
- Sex ratios to determine if there are enough terminal phase males in comparison to females for viable populations
- Local diet preferences and net effect on coral reefs, including corallivory and algal removal

Photo: Paul Asman & Jill Lenoble, Attribution 2.0 Generic license, *edited*

Photo: Initial phase *S. guacamaia*, Miguel G. Figuerola-Hernández (DRNA)

Scarus guacamaia | Rainbow parrotfish | Loro guacamayo

Range

- Widespread in the western Atlantic from Bermuda through South Florida, Bahamas, and the Caribbean to Venezuela [41]

Geographic range of *S. guacamaia* from the IUCN Red List

HABITAT

- Occur on coral reefs and mangroves [90] in depths up to 25 m [41]
- *S. guacamaia* has been described as the only Scarid to require both mangrove and coral reef habitat to complete its life cycle [90,91,92]. Juveniles had significantly greater sightings in mangroves than in any other habitat, while adult densities were significantly enhanced in reefs near mangroves, and appear to have suffered local extinctions after mangrove removal [92,93]. In Aruba, juveniles were observed exclusively in mangroves, while all adults were observed on coral reefs at ≤13 km from mangroves [91]. However, in Bermuda and Venezuela, juveniles occurred on rocky habitat, and in the Gulf of Mexico, a healthy *S. guacamaia* population was documented 300 km away from mangroves and separated by deep waters, suggesting that *S. guacamaia* does not depend on mangroves [94].

DIET

- Feed on epilithic algal turfs and endolithic algae and are proposed to be classified as excavating/bioeroding grazers [1]
- Also classified as a detritivore, with detritus/bacterial complexes and meiofauna as primary food items [41], and it feeds on sponges [Dunlap and Pawlik 1998 cited in 41]
- *S. guacamaia* feeds on similar foods to *Sparisoma viride* rather than to other herbivores in the genus *Scarus* [50]

LIFE HISTORY TRAITS

- Largest parrotfish in the Atlantic, reaching a maximum size of 120 cm, a common length of 70 cm TL, and a maximum published weight of 20 kg [41]
- Resilience: Medium with a minimum population doubling time of 1.4 – 4.4 years [95]
- Maximum age of 16 years [41]

Reproduction

- Protogynous hermaphrodite [96]
- Oviparous and have a distinct pairing when breeding [Breder & Rosen 1966 cited in 95]

Size at Sexual Maturity

Unknown

BEHAVIOR

- Sexually mature *S. guacamaia* use sun-navigation to return to their home caves at night or when threatened (Winn et al. 1964 cited in [97])
- Terminal phase males defend a territory and a harem of females [96]
- Large home range and can swim over large distances [96]

Population Tendencies

Caribbean

- The IUCN Redlist lists *S. guacamaia* as Near Threatened and describes its population trend as decreasing [41]
- Areas protected from exploitation and habitat degradation, such as Bermuda, Bonaire, and Los Roques in Venezuela, have the highest densities recorded of *S. guacamaia* [41]

Puerto Rico

The IUCN Redlist lists this species as naturally rare [41], supported by 1980-1981 vs 2001-2007 surveys in La Parguera [22]. However, anecdotal evidence suggests that this species is not as rare in Puerto Rico as once thought. Per personal communication with fisherfolk, higher abundance of *Scarus guacamaia*, in comparison to other fishing areas, have been seen on the southeastern coast of Puerto Rico.

La Parguera

Although the available data from La Parguera does not provide comparable quantitative samples, a decline in sightings of *S. guacamaia* was observed from the 1980-1981 surveys to the 2001-2007 surveys in La Parguera [Kimmel 1985 cited in 22, 22]. In 1980 – 1981, *S. guacamaia* was observed across the shelf, from mangroves to shelf edge habitats, and was observed at 50% of samples from eight surveys in mangrove sites [Kimmel 1985 cited in 22]. From 2001-2007, only two individuals of *Scarus guacamaia* were seen from 1,167 sightings [22].

PRCRMP

Scarus guacamaia appearances in the PRCRMP are low, as only one individual was documented in one transect in 2000 in Playa Mujeres, Isla Mona from 1999-2018, and one *S. guacamaia* was present outside of one transect in 1999 at Berberia Reef, Caja de Muertos [42,43].

NCRMP

S. guacamaia was documented twice in the 2016 NOAA NCRMP in southwestern Puerto Rico, at depths 10.6 m over aggregate reef and 14.2 m over patch reef [44].

Recreational Catch and Commercial Landings

Commercial Landings

Limited available catch data is available for *S. guacamaia* in Puerto Rico's commercial fisheries. Table 1 includes the adjusted landings in pounds for *S. guacamaia* from 1995-2007 [98].

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
S. guacamaia commercial landings in lbs.	354	4	0	0	13	0	0	140	617	2,128	1,855	220	0

Table 1. *Scarus guacamaia* adjusted commercial landings documented from 1995 to 2007 [98]. Note that from 1983 to 1994, no commercial landings for this species were recorded.

During 2007-2011, Commercial Fishery Statistics Program (CFSP) port samplers in Puerto Rico sampled few *S. guacamaia* individuals [45]:

Year	2007	2008	2009	2010	*2011
S. guacamaia Individuals	2	5	6	1	0

Table 1. Individual *Scarus guacamaia* measured by Puerto Rico's Commercial Fishery Landings[45]. *Note that 2011 includes partial results because data entry was not yet completed when the document was released.

Recreational Catch

Year	Fishing Mode	Fishing Area	Observed Harvest (A)	Percent Standard Error (PSE)	Reported Harvest (B1)	Percent Standard Error (PSE)	Released Alive (B2)	Percent Standard Error (PSE)	Harvest (A+B1)
2000	PRIVATE/ RENTAL BOAT	OCEAN (> 10 MI)	0	.	662	100	0	.	**662**
2003	PRIVATE/ RENTAL BOAT	OCEAN (<= 10 MI)	550	100.1	0	.	0	.	**550**
2007	SHORE	INLAND	0	.	0	.	1,842	100	**0**
2008	PRIVATE/ RENTAL BOAT	OCEAN (<= 10 MI)	0	.	707	100	0	.	**707**
2014	PRIVATE/ RENTAL BOAT	OCEAN (<= 10 MI)	1,301	79.2	0	.	0	.	**1,301**

Table 2. Recreational catch data from years 1981 – 2016 where *S. guacamaia* was recorded. This data comes from the MRIP Catch Time Series data set [38]. (*Note that large PSEs [above 50] indicate low precision).

THREATS

- Vulnerability: Moderate (42 of 100) [95]
- Possibly habitat loss [93] as well as susceptibility to overfishing, specifically to spearfishing [41]
- As a large-bodied fish, *S. guacamaia* is targeted by fishery [22]
- Reported rare in the U.S. Caribbean [22]

LOCAL PROJECTS AND PROTECTION

Projects

S. viride, Sparisoma chrysopterum, Sparisoma rubripinne, Scarus guacamaia, and *S. vetula* are covered in the DNER project *Description and Analysis of the Parrotfish Market Fishery's Supply Chain*.

Legal Protection Status

The capture and possession of the three largest Caribbean parrotfish species, *Scarus coelestinus, S. coeruleus,* and *S. guacamaia* are prohibited in U.S. Federal Waters in the Exclusive Economic Zones (EEZ) of PR [47]

RELEVANT KNOWLEDGE GAPS

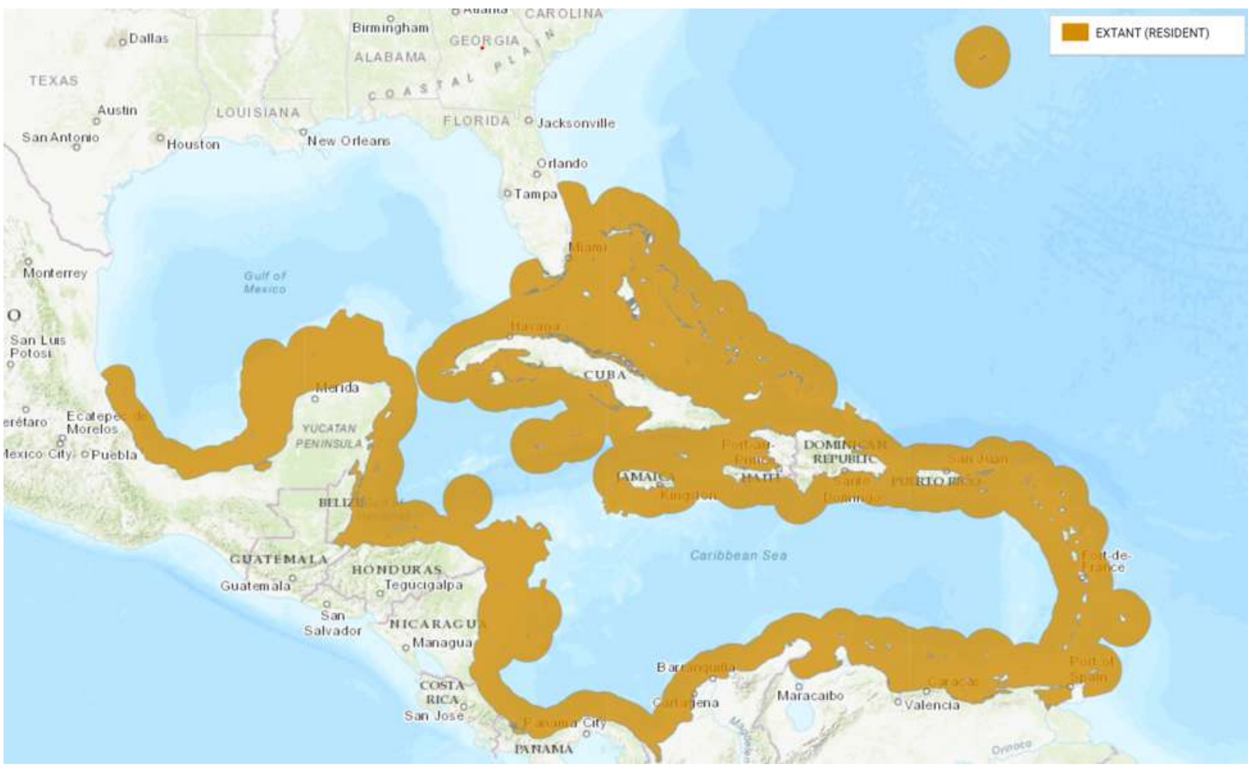
- Size at sexual maturity
- Population estimates for Puerto Rico, especially in the southeast
- Local information on if they form spawning aggregations and where
- Updated information on its appearance in both recreational and commercial fisheries

Photo: Terminal phase *S. vetula*, Kevin Bryant
CC BY-NC-SA 2.0, *edited*

Initial phase *S. vetula*

Scarus vetula | Queen Parrotfish | Loro reina

Range



Geographic range of *S. vetula* from the IUCN Red List

Habitat

- Occur in depths up to 25 m [99]
- Reef associated [99] and strongly associated with architecturally complex coral reefs [1]

DIET

- Classified as a scraper [11]
- Prefers consuming turf algae [11] but also consumes live coral [Rotjan & Lewis 2008 cited in 1]

LIFE HISTORY TRAITS

- Maximum size: 61 cm TL [47], common length is 32 cm TL [Randall 1978 cited in 100]
- In the U.S. Caribbean, the maximum age is 15 years (Virginia Shervette, *pers. comm.*; In Bermuda, the maximum age was 20 years [JH Choat *pers. comm.* 2009 cited in 99]
- All females in genus *Scarus* change into male if they live long enough [Robertson and Warner 1978 cited in 56]
- Initial phase fish were about 4 times as common as terminal phase fish, and primary males were present but rare, and sex ratio was biased towards females [101]

Reproduction

- Protogynous hermaphrodite [99]
- Observed pair spawning, where one terminal phase and one initial phase move 2 to 3 m rush upward from the main group and release gametes at the rush apex [102]
- Spawning has been documented throughout the year and only in the morning [57]

Size at Sexual Maturity

The only information available about the length of at 50% maturity (L_{50}) of *S. vetula* is from 1974-1975 in Panama, where males were reported to have an L_{50} of 21 cm TL and females 16 cm TL [Robertson and Warner 1978 cited in 56]. Sexual transition was reported to occur at 21 cm TL [Robertson and Warner 1978 cited in 56].

BEHAVIOR

- In the Florida Keys, feed on substrates with high structural complexity [1]
- Prefer feeding on flat substrate surfaces [11]
- Take quick bites and most of the time does not leave any scars from grazing [11]
- Often seen in groups of one terminal male with several young adults, most of which are probably females [99]
- There are territory-defending terminal phase and smaller nonterritorial terminal phase males [101]. Larger terminal phase fish occur alone defending a territory where some females live, while initial phase fish can be solitary or in small groups. There are also smaller nonterritorial terminal phase fish.
- Secrete a protective mucous cocoon to sleep, which prevent parasite infestation [103,104]

Population Tendencies

Caribbean

- Classified as "Least Concern" by the IUCN Red List and documented as common throughout its range [L. Rocha pers. comm. 2009 cited in 99]
- Near densely populated areas around Haiti and Jamaica, there have been severe population declines in reefs [Hawkins and Roberts 2004 cited in 99]

Puerto Rico

From 1976 to 1980, southwest off Guanica, *S. vetula* had approximately a tenth of the abundance of *S. taeniopterus* and *Sparisoma viride* [57]. Size classes from 10 cm Standard Length (SL) to 26 cm SL were documented, and the most common was 23 cm SL.

La Parguera

Surveys taken from 2001-2007 documented a mean abundance of 0.02 individuals/ 100 m^2 and a mean biomass of 4.3g/ 100 m^2 [22].

PRCRMP

Sightings and densities of *S. vetula* were higher in PRCRMP surveys prior to 2008 in comparison to 2008 until 2019 [72]. A total of 42 sites were monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *S. vetula* density of 0.05 individuals/ 30 m^2 [85,25]. Only 13 individuals were sized during this period, none of which were recruitment size, but the size classes with the highest percentage of individuals were 6-10 cm TL and 11-15 cm TL, both at 23% of individuals. No individuals above 40 cm TL were documented during this period.

NCRMP

Scarus vetula was present in the 2016 NCRMP and the majority of individuals appeared in aggregate shallow or aggregate deep reefs [105].

Recreational Catch and Commercial Landings

Scarus vetula was not separated by species in commercial fisheries landings from 1983 to 2007, and so it likely appears under the group "parrotfish." It does appear in commercial fisheries, as port samplers have documented this species in various years [51]. *Scarus vetula* also appears in recreational fisheries [38].

Threats

- Rated to have a low to moderate intrinsic vulnerability to fishing based on its life history and ecological characteristics [87 cited in 100]
- Overfishing, which can also skew the sex ratio [56]
- Severe population declines near densely populated areas [Hawkins and Roberts 2004 cited in 99]

Local Projects and Protection

Projects

Scarus vetula is one of the parrotfishes covered in the DNER project *Description and Analysis of the Parrotfish Market Fishery's Supply Chain*.

Dr. Virginia Shervette of the University of South Carolina is investigating age, growth, and reproductive biology (including size at sexual maturity and size at sexual transition), for seven parrotfish species (*Sparisoma viride, S. chrysopterum, S. aurofrenatum, S. rubripinne, Scarus vetula, S. taeniopterus, S. iseri*) in Puerto Rico, St. Thomas, and St. Croix.

Legal Protection Status

For recreational fisheries within U.S. Federal Waters in the Exclusive Economic Zone (EEZ) of Puerto Rico, there is a 2 parrotfish per person per day or 6 parrotfish per vessel per day regulation, which applies to the following species: *Sparisoma aurofrenatum, Scarus taeniopterus, Scarus vetula, Scarus iseri, Sparisoma chrysopterum, Sparisoma viride,* and *Sparisoma rubripinne* [47].

Proposed

The DNER's Regulation Number 6766 of 2004, created to regulate vulnerable and endangered species in the Commonwealth of Puerto Rico, was proposed to be updated in 2016 [89]. The new proposed Appendix I. List of Vulnerable and Endangered Species, included *Scarus vetula* under the category Endangered, defined as a species with a high risk of extinction in the wild in the medium term, because of overfishing.

In 2013, the Regulatory Amendment 4 to the Fishery Management Plan for the Reef Fish Fishery of Puerto Rico and the USVI listed alternatives for minimum size limits for commercial and recreational parrotfish fisheries, which includes *S. vetula* [60]. However, the preferred alternatives pertain only to St. Croix, while alternatives pertaining to Puerto Rico are listed but are not preferred.

Relevant Knowledge Gaps

- Fisheries-independent monitoring surveys which measure the size at sexual maturity and sexual transition in Puerto Rico
- A comparison of populations and their size and age structure over time, representative of Puerto Rico
- Additional age and growth research
- Updated and species-specific information on catch in commercial and recreational fisheries
- A comparison of populations and their size structure over time, representative of Puerto Rico

- Sex ratios to determine if there are enough terminal phase males in comparison to females for viable populations
- Local diet preferences and net effect on coral reefs, including corallivory and algal removal

Juvenile *S. taeniopterus*
Photo: DNER PRCRMP

Initial phase *S. taeniopterus (edited)*
Photo: Paul Asman & Jill Lenoble, CC by 2.0

Terminal phase *S. taeniopterus*
Photo: DNER PRCRMP

SCARUS TAENIOPTERUS | PRINCESS PARROTFISH | LORO PRINCESA

RANGE

Geographic range of *S. taeniopterus* from the IUCN Red List

HABITAT

- Associated with coral reefs and seagrass [106], and most common over mid- and outer-shelf zones with highly contiguous colonized hardbottom [22]

- In La Parguera, it appears to be geographically restricted, as it was uncommon or absent in nearshore areas, seagrasses, and unvegetated sediments [22]
- Occur in depths up to 25 m [106]

DIET

- Classified as a scraping grazer since it takes small bites and scrapes the substrate as it feeds, however it does not leave scrape marks [107]
- In Curaçao, approximately 80% of all bites were taken from surfaces dominated by turf algae, and the second highest target surface was dominated by *Dictyota* spp. [7]

LIFE HISTORY TRAITS

- Maximum size is approximately 33 cm [47]
- Maximum age in the U.S. Caribbean is 11 years (Virginia Shervette, *personal communication*)
- Rated as having high resilience, with a minimum population doubling time less than 15 months [Froese et al. 2017 cited in 108]

Reproduction

- Protogynous hermaphrodite [106]
- In southwestern Puerto Rico, it spawns in pairs only in the morning in most months throughout the year, but does not appear to spawn daily like other parrotfishes [57]

Size and Age at Sexual Maturity

Length at 50% maturity (L_{50}):

- 12 cm TL in U.S. Caribbean (Virginia Shervette, *pers. comm.*)
- 17 cm FL in Jamaica [Reeson 1983 cited in 109]
- 15 cm FL in St. Lucia [Hawkins et al. 2007 cited in 109]

Age at 50% maturity (A_{50}):

- 1.4 years in U.S. Caribbean (Virginia Shervette, *pers. comm.*)

BEHAVIOR

- Considered to be significant in contributing to the overall grazing activity on Caribbean reefs [7]
- Can keep newly established algal communities in an early successional stage, which allows for coral and CCA growth, however, in already established communities, it can facilitate later successional macroalgae [48]
- Forms schools [106]

- Secretes a protective mucous cocoon to sleep, which prevent parasite infestation [103 cited in 108,104]

POPULATION TENDENCIES

Caribbean

- Common and abundant throughout its range [L. Rocha pers. comm. 2009 cited in 106]
- Listed as "Least concern" by the IUCN Red List [106]

Puerto Rico

La Parguera

- From 2001 to 2007, *S. taeniopterus* had a mean abundance of 1.7 ± 0.16 individuals/ 100 m^2 and mean biomass of 93.1 ± 10.7g/ 100 m^2 [22]
- Between 2001 and 2007, *S. taeniopterus* adults were seen more frequently than juveniles, and the majority were in size class 10-15 cm, and individuals above 30 cm FL were rare [22]
- Both biomass and abundance were significantly higher in 2007 in comparison to 2002 [22]

PRCRMP

A total of 42 sites were monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *S. taeniopterus* density of 1.78 individuals/ 30 m^2 [85,25]. During this period, 189 individuals were sized, 20% of which were recruitment size. The size class with the highest percentage of individuals was 6-10 cm, at 38%. No individuals above 30 cm were documented during this period.

NCRMP

Scarus taeniopterus was commonly seen in the 2016 NCRMP, and the majority of individuals appeared in deep (12-30 m) waters, over aggregate reefs, pavement, or patch reefs [105].

Recreational Catch and Commercial Landings

Scarus taeniopterus was not separated by species in commercial fisheries landings from 1983 to 2007, and so it likely appears under the group "parrotfish." It does appear in commercial fisheries, as port samplers have documented this species in various years [51]. *Scarus taeniopterus* also appears in recreational fisheries [38].

THREATS

- Rated to have a low intrinsic vulnerability to fishing based on its life history and ecological characteristics [87 cited in 108]

- Overfishing, which could skew a population's sex ratio [56]

Local Projects and Protection

Projects

Dr. Virginia Shervette of the University of South Carolina is investigating age, growth, and reproductive biology (including size at sexual maturity and size at sexual transition), for seven parrotfish species (*Sparisoma viride, S. chrysopterum, S. aurofrenatum, S. rubripinne, Scarus vetula, S. taeniopterus, S. iseri*) in Puerto Rico, St. Thomas, and St. Croix.

Legal Protection Status

For recreational fisheries within U.S. Federal Waters in the Exclusive Economic Zone (EEZ) of Puerto Rico, there is a 2 parrotfish per person per day or 6 parrotfish per vessel per day regulation, which applies to the following species: *Sparisoma aurofrenatum, Scarus taeniopterus, Scarus vetula, Scarus iseri, Sparisoma chrysopterum, Sparisoma viride,* and *Sparisoma rubripinne* [47].

Proposed

The DNER's Regulation Number 6766 of 2004, created to regulate vulnerable and endangered species in the Commonwealth of Puerto Rico, was proposed to be updated in 2016 [89]. The new proposed Appendix I. List of Vulnerable and Endangered Species, included *Sparisoma viride* under the category Endangered, defined as a species with a high risk of extinction in the wild in the medium term, because of overfishing.

Relevant Knowledge Gaps

- Fisheries independent surveys which measure the size at sexual maturity and at phase change in Puerto Rico
- A comparison of populations and their size structure over time, representative of Puerto Rico
- Sex ratios to determine if there are enough terminal phase males in comparison to females for viable populations
- Local diet preferences and effect on coral reefs through algal removal

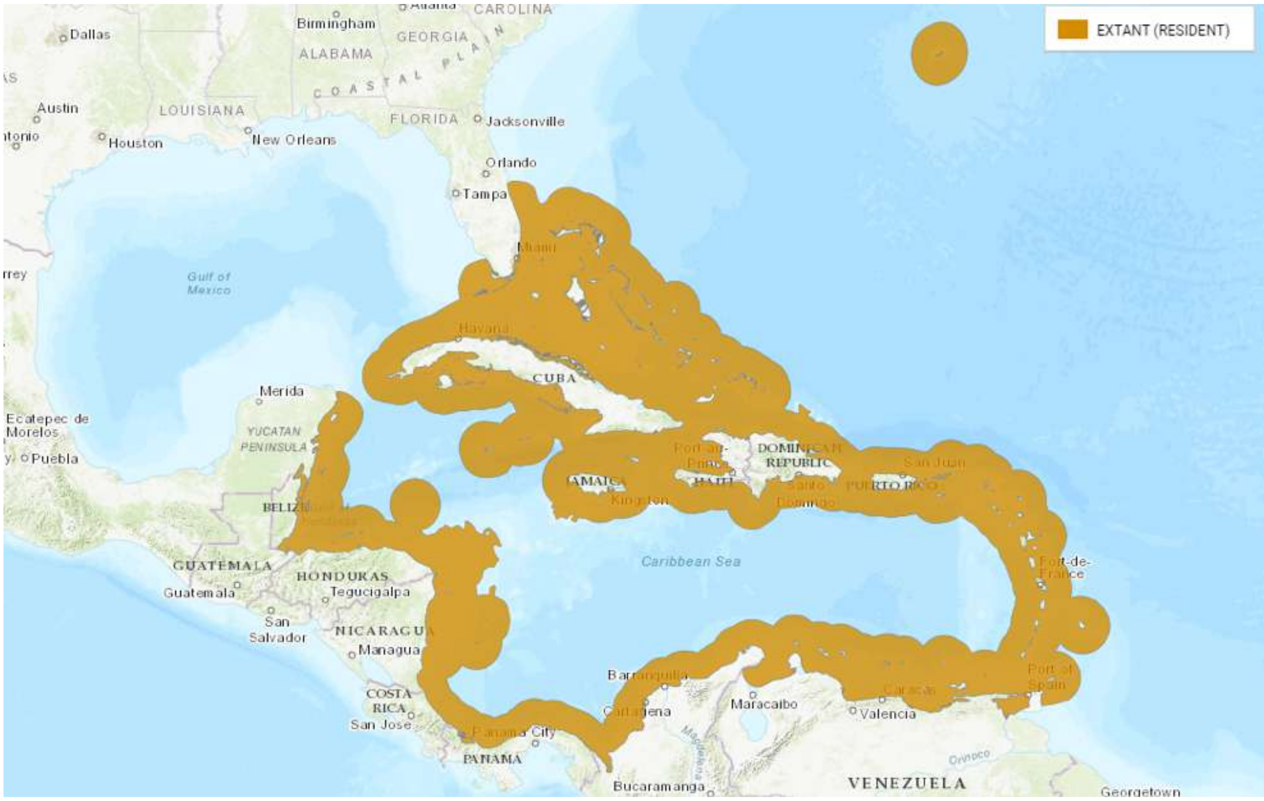
Juvenile or initial phase *S. iseri*

Terminal phase *S. iseri*
Both photos: Garcia-Sais et al. for DNER

SCARUS ISERI | STRIPED PARROTFISH | LORO LISTADO

This species was previously known as *Scarus croicensis* and *Scarus iserti* [110].

RANGE



Geographic range of *S. iseri* from the IUCN Red List

HABITAT

- Associated with reefs and seagrasses [110], and in La Parguera, *S. iseri* has higher biomass and abundance in highly rugose colonized hardbottom [22]
- Occur in depths from 3 to 30 m [110]
- Use mangroves and seagrasses as nursery habitat for juveniles [111], however it can also use reef as an alternate nursery [112]
- In Belize, both density and biomass of *S. iseri* is positively correlated with reef complexity [113,49]

DIET

- Consumes algae and is categorized as a scraper [1,17]

LIFE HISTORY TRAITS

- Maximum size is 25.4 cm [47]
- Maximum age of 11 documented for the U.S. Caribbean (Virginia Shervette, *pers. comm.*)

Reproduction

- Protogynous hermaphrodite [110]
- Terminal phase males spawn individually with striped females [110,114], while sexually mature males in the initial phase reproduce in spawning aggregations [110]
- In USVI and PR, *S. iseri* usually mate in pairs at deep spawning sites, and do not hold territories [Randall and Randall, 1963 and Barlow 1975 cited in 56]
- Spawning aggregations of *S. iseri* were documented on the southwest coast of Guanica Bay [57]

Size at Sexual Maturity

- In Jamaica, the length of at 50% maturity (L_{50}) for *S. iseri* is 15 cm FL [Reeson 1983 cited in 109]
- In Puerto Rico, size of sexual transition is 14 cm, and in Jamaica, it is as small as 10 cm [56]
- Smallest initial male collected from the U.S. Caribbean was 8 cm (Virginia Shervette, *pers. comm.*)

BEHAVIOR

- Forms schools [110]
- Territorial species [49], however they have small territory sizes in comparison to other parrotfishes, at a mean of 41 to 120 m^2 [113]

Population Tendencies

Caribbean

- Very common and is the most abundant parrotfish in the Caribbean [110]
- Listed as "Least Concern" by the IUCN Red List [110]
- Biomass and densities are enhanced by the availability of mangroves and/or seagrass beds as nursery habitat [93,115]

Puerto Rico

La Parguera

- *Scarus iseri* is the most commonly occurring fish across all major habitat types at La Parguera [22]
- From 2001 to 2007, *S. iseri* had a mean abundance of 6.0 ± 0.39 individuals/ 100 m^2 and mean biomass of 110.2 ± 7.9g/ 100 m^2 [22]
- Between 2001 and 2007, *S. iseri* juveniles were seen more frequently than adults, and the majority were of recruitment size (<5 cm) and size class 5-10 cm and individuals above 25 cm FL were rare [22]

PRCRMP

A total of 42 sites were monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *S. iseri* density of 1.23 individuals/ 30 m^2 [85,25]. During this period 139 individuals were sized, 26% of which were recruitment size. The size class with the highest percentage of individuals was 6-10 cm, at 32%. No individuals above 30 cm were documented during this period.

NCRMP

Scarus iseri was commonly seen in the 2016 NCRMP, and the majority of individuals appeared over aggregate reefs in deep (12-30 m) waters [105].

Recreational Catch and Commercial Landings

Scarus iseri was not separated by species in commercial fisheries landings from 1983 to 2007, and so it may appear under group "parrotfish." Port samplers documented this species only once in 2009, so it may not be common in commercial fisheries [45]. It also appears but is uncommon in recreational fisheries [38].

Threats

- Predation by lionfish [17]

Local Projects and Protection

Projects

Dr. Virginia Shervette of the University of South Carolina is investigating age, growth, and reproductive biology (including size at sexual maturity and size at sexual transition), for seven parrotfish species (*Sparisoma viride, S. chrysopterum, S. aurofrenatum, S. rubripinne, Scarus vetula, S. taeniopterus, S. iseri*) in Puerto Rico, St. Thomas, and St. Croix.

Legal Protection Status

For recreational fisheries within U.S. Federal Waters in the Exclusive Economic Zone (EEZ) of Puerto Rico, there is a 2 parrotfish per person per day or 6 parrotfish per vessel per day regulation, which applies to the following species: *Sparisoma aurofrenatum, Scarus taeniopterus, Scarus vetula, Scarus iseri, Sparisoma chrysopterum, Sparisoma viride,* and *Sparisoma rubripinne* [47].

Proposed

In 2013, the Regulatory Amendment 4 to the Fishery Management Plan for the Reef Fish Fishery of Puerto Rico and the USVI listed alternatives for minimum size limits for commercial and recreational parrotfish fisheries, which includes *S. viride* [60]. However, the preferred alternatives pertain only to St. Croix, while alternatives pertaining to Puerto Rico are listed but are not preferred.

Relevant Knowledge Gaps

- Fisheries independent surveys which measure the size at sexual maturity and at phase change in Puerto Rico
- A comparison of populations and their size structure over time, representative of Puerto Rico
- Sex ratios to determine if there are enough terminal phase males in comparison to females for viable populations
- Local diet preferences and effect on coral reefs

ACANTHURUS TRACTUS | FIVE-BAND SURGEONFISH | CIRUJANO PARDO

This species was previously known as *Acanthurus bahianus*, however, it was revalidated as a separate species and named *Acanthurus* tractus, which is different from *A. bahianus,* which is now considered endemic to Brazil [116].

RANGE

Geographic range of *A. tractus* from the [IUCN Red List]

HABITAT

- Inhabits shallow rocky and coral reefs, as well as inshore rocky areas with sand patches [116], and the highest abundance and biomass was seen over colonized hardbottom on mid- and outer-shelf zones in La Parguera [22]
- Occurs in depths from 2 to 40 m [116]

DIET

- Classified as a scraper [46] and mainly consumes turf algae [9], detritus [46], and *Dictyota* [7] and sometimes grazes on seagrass beds [Bernal and Rocha 2011 cited in 116]
- Feeds on red macroalgae species that other herbivores, such as parrotfishes, did not graze on [117]
- Suspected to have diverse and flexible feeding patterns [50]

LIFE HISTORY TRAITS

- Maximum length is 38.1 cm Standard Length (SL) [Humann 1994 cited in 118]
- Maximum age is reported to be 31 years [Choat & Robertson 2002 cited in 118]
- Larvae planktonic phase can be up to 69 days [Castellanos Gel et al. 2012 cited in 116]

Reproduction

- Pair and group spawning [57], with as many as 20,000 individuals present for spawning [Colin 1985 cited in 57]
- Peak spawning months in southwestern Puerto Rico were from December through March [57]
- Spawning aggregations of *A. tractus* on the southwest coast of Guanica Bay were documented [57]

Size at Sexual Maturity

Length at 50% maturity (L_{50}):

- 15.5 cm FL in Jamaica [Reeson 1983 cited in 109]

BEHAVIOR

- Diurnal [118]
- Usually swims in schools of five or more individuals [118]
- Considered to be a significant contributor to grazing activity on Caribbean coral reefs [7]
- *Acanthurus tractus* does not regulate overall macroalgae cover and biomass as some parrotfish species might, but are important for preventing blooms of macroalgae that are avoided by other herbivores such as parrotfishes [14]

POPULATION TENDENCIES

Caribbean

- Common and listed as "Least Concern" by the IUCN Red List [116]

Puerto Rico

La Parguera

- *Acanthurus tractus* was the most abundant surgeonfish documented in La Parguera from 2001-2007 [22]
- Between 2001 and 2007, *A. tractus* had a mean abundance of 1.8 ± 0.1 individuals in 100 m^2 and mean biomass of 119.9 ± 8.0g/ 100 m^2 [22]
- Populations of *A. tractus* were significantly higher in 2007 in comparison to 2002 [22]
- The majority of individuals documented between 2001 and 2007 were size 10-15 cm, and then 15-20 cm, however, juveniles (<10 cm)were also documented [22]

PRCRMP

A total of 42 sites were monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *A. tractus* density of 0.63 individuals/ 30 m^2, the highest average density of the three surgeonfishes during this cycle [85,25]. Approximately 45% of *A. tractus* individuals documented during this period were of size class 11-15 cm, and the next highest percentage at 33% were 6-10 cm. 11% were of recruitment size (1-5 cm) and no individuals above 25 cm were documented.

NCRMP

Acanthurus tractus was commonly seen in the 2016 NCRMP, and the majority of individuals appeared in deep (12-30 m) waters, over pavement or aggregate reefs or pavement [105].

Recreational Catch and Commercial Landings

Surgeonfishes are considered "trash fish" in Puerto Rico fisheries, which are fish with little to no market value [Matos-Caraballo & Sadovy 1990 cited in 51]. All three surgeonfishes are grouped together in commercial fisheries reporting data so it would be difficult to determine which species were part of capture, however, between 2012 and 2017, surgeonfishes were not reported in commercial fisheries. Even so, port samplers in commercial fisheries measured three *A. tractus* individuals in 2012 [45]. Surgeonfishes are also not targeted in recreational fisheries.

Acanthurus tractus was reported in ornamental fisheries from 2002 to 2005, with 179 captured during this time and sold at an average of $0.88 each [28].

THREATS

- Potential population reduction due to overfishing

- Large proportions of surgeonfishes are caught as juveniles because of their body depth [Robichaud et al. 1999; Hawkins et al. 2007 cited in 109]
- Predation by lionfish [119]

LOCAL PROJECTS AND PROTECTION

Projects

No current projects involving *A. tractus* in Puerto Rico were identified

Legal Protection Status

In recreational fisheries within Puerto Rico's Exclusive Economic Zone (EEZ), there is a 1 surgeonfish per person per day or maximum of 4 surgeonfish per vessel per day limit [120]. Surgeonfish are also part many species groups in an aggregate bag limit of 5 fish per person per day or 15 fish per vessel per day if there are 3 or more people on board.

Proposed

The DNER's Regulation Number 6766 of 2004, created to regulate vulnerable and endangered species in the Commonwealth of Puerto Rico, was proposed to be updated in 2016 [89]. The new proposed Appendix I. List of Vulnerable and Endangered Species, included *A. tractus* under the category Data Deficient, with the explanation that population numbers are suspected to have decreased due to overfishing.

All three surgeonfishes are proposed for management in Puerto Rico's Exclusive Economic Zone (EEZ) under the April 2019 Comprehensive Fishery Management Plan (FMP) by the Caribbean Fisheries Management Council [121].

RELEVANT KNOWLEDGE GAPS

- A market analysis of this species in Puerto Rico
- A comparison of populations and their size structure over time, representative of Puerto Rico
- Local information on diet, feeding behavior, and effect on coral reefs

Photo: D Ross Robertson, Smithsonian Institution

ACANTHURUS CHIRURGUS | DOCTORFISH | BARBERO RAYADO

RANGE

Occurs throughout the western Atlantic, although rare north of Florida juveniles occur in Massachusetts [122]. Present in the Gulf of Mexico and throughout the Caribbean Sea, south to São Paulo, Brazil [122]. Although recorded in West Africa, these are likely misidentifications of *A. monroviae* [L. Rocha pers. comm. 2010 cited in 122].

Geographic range of *A. chirurgus* from the IUCN Red List

HABITAT

- Occurs on coral reefs and rocky areas, while juveniles use seagrass and mangroves as nurseries [122]
- In La Parguera, the highest densities and biomass occurs over colonized hardbottom [22]
- Occurs in depths from 2 to 70 m [122]

DIET

- Classified as a scraper [46]
- Consumes mostly algae and detritus, and occasionally seagrass [122,46], and also consumes inorganic sediment [123]

LIFE HISTORY TRAITS

- Maximum size is 39 cm TL [Figueredo et al. 2002 cited in 109]
- Mean maximum age was from 7 to 16 years, with a maximum age of 30 years [Mutz 2006 cited in 122], but it has high turnover rates [JH Choat pers comm 2010 cited in 122]
- Reaches terminal size around 4 years [122]
- Pelagic larval stage from 45 to 71 day [Rocha et al 2002 cited in 122]
- Settles on reef when 2.7 cm length [Robertson 1992 cited in 122]

Reproduction

No published information was found about *A. chirurgus* spawning

Size at Sexual Maturity

- Length at 50% maturity (L_{50}): 23 cm FL in Jamaica [Reeson 1983 cited in 109]

POPULATION TENDENCIES

Caribbean

- Common and listed as “Least Concern” by the IUCN Red List [122]

Puerto Rico

La Parguera

- *Acanthurus chirurgus* had the lowest abundance and biomass of the surgeonfishes from 2001-2007 [22]
- Between 2001 and 2007, *A. chirurgus* had a mean abundance of 0.54 ± 0.07 individuals in 100 m^2 and mean biomass of 54.8 ±11.5g/ 100 m^2 [22]
- The majority of individuals documented between 2001 and 2007 were size 15-20 cm, and then 20-25 cm, however, juveniles (<10 cm) were also documented [22]

PRCRMP

A total of 42 sites total were monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *A. chirurgus* density of 0.46 individuals/ 30 m^2, the lowest average density of the three surgeonfishes during this cycle [85,25]. Approximately 45% of *A. chirurgus* individuals documented during this period were of size class 11-15 cm, and the next highest percentage at 26% were 6-10 cm. Of these individuals, 15% were of recruitment size (1-5 cm) and no individuals above 20 cm were documented.

NCRMP

Acanthurus chirurgus was not as common as the other two surgeonfishes in the 2016 NCRMP, but the majority of reported individuals appeared in deep (12-30 m) pavement and shallow patch reef [105].

Recreational Catch and Commercial Landings

Surgeonfishes are considered "trash fish" in Puerto Rico fisheries, which are fish with little to no market value [Matos-Caraballo & Sadovy 1990 cited in 51]. All three surgeonfishes are grouped together in commercial fisheries reporting data so it would be difficult to determine which species were part of capture. However, between 2012 and 2017, surgeonfishes were not reported in commercial fisheries. Even so, port samplers in commercial fisheries measured just one *A. chirurgus* individual in 2015 [45]. Surgeonfishes are also not targeted in recreational fisheries.

Acanthurus chirurgus was listed as a species reported in the marine ornamental fisheries from 2002 to 2005, however, data was not available for this species and it is not suspected to be a large part of ornamental fisheries [28].

THREATS

- Potential population reduction as there is localized areas where populations have declined due to heavy fishing [122]
- Large proportions of surgeonfishes are caught as juveniles because of their body depth [Robichaud et al. 1999; Hawkins et al. 2007 cited in 109]

LOCAL PROJECTS AND PROTECTION

Projects

No current projects involving *A. chirurgus* in Puerto Rico were identified

Legal Protection Status

In recreational fisheries within Puerto Rico's Exclusive Economic Zone (EEZ), there is a 1 surgeonfish per person per day or maximum of 4 surgeonfish per vessel per day limit [120]. Surgeonfish are also part of many species' groups in an aggregate bag limit of 5 fish per person per day or 15 fish per vessel per day if there are 3 or more people on board.

Proposed

The DNER's Regulation Number 6766 of 2004, created to regulate vulnerable and endangered species in the Commonwealth of Puerto Rico, was proposed to be updated in 2016 [89]. The new proposed Appendix I. List of Vulnerable and Endangered Species, included *A. chirurgus* under the category Vulnerable, due to overfishing.

All three surgeonfishes are proposed for management in Puerto Rico's Exclusive Economic Zone (EEZ) under the April 2019 Comprehensive Fishery Management Plan (FMP) by the Caribbean Fisheries Management Council [121].

RELEVANT KNOWLEDGE GAPS

- A market analysis of this species in Puerto Rico
- A comparison of populations and their size structure over time, representative of Puerto Rico
- Local information on diet, feeding behavior, and effect on coral reefs
- Information on reproduction and spawning aggregations

Juvenile *A. coeruleus*
Photo: Garcia-Sais et al. for DNER

ACANTHURUS COERULEUS | BLUE TANG | BARBERO AZUL

RANGE

Geographic range of *A. coeruleus* from the IUCN Red List

Habitat

- Inhabits coral reefs, rocky areas, and seagrasses [124], and the highest abundance and biomass in La Parguera was seen over colonized hardbottom [22]
- Occurs in depths up to 60 m [124]
- In Barbados, juveniles were rare on reef flats and mainly occurred on the reef crest and spurs [125]

Diet

- Classified as a browser [46]
- The majority of its diet consists of turf algae [3], but it also consumes *Dictyota* spp. [7] and seagrass [46]
- Unlike the *A. chirurgus* and *A. tractus, A. coeruleus* has a thin-walled stomach and usually does not ingest sand [123]

Life History Traits

- Maximum length is 38.1 cm [47]
- Terminal size reached around age 4 [124]
- Mean maximum age ranges from 8 to 37 years, with a maximum age of 43 years old [Mutz 2006 cited in 124]
- Pelagic larval stage duration of 36 to 57 days [Rocha et al. 2002 cited in 124]
- At 2.67 cm, larvae settles on reefs [Roberson 1992 cited in 124]

Reproduction

- Pair and group spawn, and group spawning occurs most of the year [57]
- Spawning aggregations of 6,000 to 7,000 individuals were documented in the late afternoon on the southwest coast of Guanica Bay [57]

Size at Sexual Maturity

- Length at 50% maturity (L_{50}): 15 cm FL in Jamaica [Reeson 1983 cited in 109]

Behavior

- Diurnal [126]
- Adults form large foraging schools, occasionally with other surgeonfishes [124]
- Adults are either territorial or non-territorial [124]
- In Barbados, juveniles were solitary and had stable home ranges which increased with body size [125]

POPULATION TENDENCIES

Caribbean

- Common and has a stable population throughout its range [124]
- Listed as "Least Concern" by the IUCN Red List [124]

Puerto Rico

La Parguera

- The majority of individuals documented between 2001 and 2007 were size 10-15 cm, and then 15-20 cm, however, juveniles were also documented [22]
- Between 2001 and 2007, *A. coeruleus* had a mean abundance of 0.83 ± *0.10 individuals in 100 m² and mean biomass of 80.0 ± 17.5g/ 100 m²* [22]

PRCRMP

A total of 42 sites were monitored in the 2018 and 2019 PRCRMP cycle, which documented an average *A. coeruleus* density of 0.52 individuals/ 30 m² [85,25]. Approximately 41% of *A. coeruleus* individuals documented during this period were of size class 11-15 cm, and the next highest percentage at 37% were 6-10 cm. Of these individuals, 13% were of recruitment size (1-5 cm) and no individuals above 25 cm were documented.

NCRMP

In a total of 240 surveys, the 2016 NCRMP surveys documented a mean density of 3.78 ± 0.13 *A. coeruleus* individuals/ 177 m² [44]. The size class of approximately 58% of all individuals was 10-20 cm, with a maximum size of 25 cm [44]. The majority of individuals occurred over shallow or deep (12-30 m) aggregate reef [105].

Recreational Catch and Commercial Landings

Surgeonfishes are considered "trash fish" in Puerto Rico fisheries, which are fish with little to no market value [Matos-Caraballo & Sadovy 1990 cited in 51]. All three surgeonfishes are grouped together in commercial fisheries reporting data so it would be difficult to determine which species were part of capture, however, between 2012 and 2017, surgeonfishes were not reported in commercial fisheries. Surgeonfishes are also not targeted in recreational fisheries.

A. coeruleus commonly occurs in Puerto Rico's ornamental fisheries. It was the eighth most captured ornamental species in Puerto Rico between 2010 and 2015, with a total of 5,283 individuals captured [127]. The average price per individual for *A. coeruleus* was over $3.00 [127].

THREATS

- Potential population reduction due to overfishing. Surgeonfishes are heavily fished in some areas of the Caribbean [44]
- Large proportions of surgeonfishes are caught as juveniles because of their body depth [Robichaud et al. 1999; Hawkins et al. 2007 cited in 109]

LOCAL PROJECTS AND PROTECTION

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