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Status of Napoleon wrasse in Laamu Atoll, Maldives, after three decades of protection

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ABSTRACT: The Napoleon or humphead wrasse *Cheilinus undulatus* is a large, globally threatened coral reef fish. In recognition of suspected declines and considering its ecotourism importance, the Maldives was the first country to ban its export in 1995. The present study, a quarter-century after the ban, documents the species around Laamu Atoll, southern Maldives, using dive guides and researchers to conduct surveys during commercial dive tourism trips. Data were collected on abundance, body size, and potential spawning sites in 4 habitat types: channels (reef passes to open ocean), inner reefs (reef slopes inside the atoll), outer reefs (reef slopes outside the atoll), and faros (isolated submerged reefs inside the atoll). Abundance was recorded in number of fish per hectare, and fish length was classified as <100 cm, ≥100 cm, or unknown size. Possible spawning aggregation sites were identified based on multiple occasions of temporarily increased fish density associated with large male presence. Mean densities ranged from 6.02 fish ha^{-1} in channels, 2.65 and 2.29 fish ha^{-1} in outer and inner reefs, respectively, and 0.73 fish ha^{-1} in faros. These densities are consistent with those found in unexploited areas in similar habitats elsewhere and indicate successful protection of the species on Laamu Atoll. The data highlight the significance of reef channel habitat for this species as important megafauna and the need for management to conserve both species and channel habitats. The value of non-specialist observers for conducting labour-intensive surveys on large, wide-ranging species is demonstrated.

KEY WORDS: *Cheilinus undulatus* · Endangered reef fish · Protected species · Non-specialist observation surveys · Reef channels

1. INTRODUCTION

The Napoleon or humphead wrasse *Cheilinus undulatus* is one of the largest coral reef-associated fishes, reported to reach at least 160 cm total length (TL) and about 90 kg (J. H. Choat pers. comm.). It is widely distributed across much of the tropical Indo-Pacific region but is naturally uncommon, with recorded maximum adult densities in unfished areas and outside of spawning aggregations rarely exceeding 10 fish ha^{-1} and usually much less (Myers 1999, Sadovy et al. 2003). It takes 4–6 yr for individuals to mature and they can live for at least 30 yr. The species is a protogynous hermaphrodite, with most fish first reproducing as females. Only when older and considerably larger (at about 90 cm) do some individuals start to become males (Choat et al. 2006, Sadovy de Mitcheson et al. 2010, Andrews et al. 2015). Adults are most often encountered on outer reef slopes, reef drop-offs, and in reef channels to a depth of at least 100 m (Randall et al. 1978, Allen & Swainston 1988, Sluka 2000, Pearse et al. 2018). They

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spawn at specific sites where few to 100 or more fish aggregate (Colin 2010). Napoleon wrasses feed mainly on invertebrates, including the crown-of-thorns starfish *Acanthaster planci* (Randall et al. 1978, Sill & Dawson 2021).

Napoleon wrasses are of interest to humans both as food and for their charismatic nature, which is much appreciated by divers. However, strong demand in some domestic markets from small-scale fisheries and international trade for the Chinese luxury seafood market has led to steep declines in the species in parts of its range and the widespread disappearance of large adults (predominantly males) from some areas in the last 2–3 decades (Sadovy et al. 2003, Hamilton et al. 2019, Sadovy de Mitcheson et al. 2019). Today, individuals larger than 1 m are rarely seen except when the species is protected or 'lightly' fished (Sadovy de Mitcheson et al. 2017, Hamilton et al. 2019, Pearse et al. 2018). Due to concerns about declines in some populations and in recognition of the natural vulnerability of Napoleon wrasse to unmanaged fishing, various species-specific management measures have been introduced for this 'conservation-dependent' species (Gillett 2010), including in Australia, Indonesia, Maldives, Niue, Seychelles, Palau, Philippines, Fiji, Kiribati, Malaysia, New Caledonia, Seychelles, Solomon Islands, and American Samoa, amongst others (Russell 2004, Aumeeruddy & Robinson 2006, Gillett 2010, Hau 2022). In 2004, the Napoleon wrasse was included in Appendix II of the Convention on International Trade in Endangered Species of Flora and Fauna (CITES). It is the first reef food-fish to be so designated and was categorized as Endangered on the International Union for Conservation of Nature (IUCN) Red List in 2004 based on a population reduction of at least 50% over 3 generations (Russell 2004).

The Maldives was the first country to ban the capture, sale, and export of the Napoleon wrasse in 1995. The export ban was prompted by concerns from divers and dive guides who recognised that it was becoming rare at dive sites. The species was increasingly fished for domestic use but was particularly targeted for exports to Hong Kong and mainland China as luxury live seafood (Shakeel 1995, Faiz 1997, Lau & Parry-Jones 1999). Dive guides in the late 1980s and early 1990s found Napoleon wrasse to be popular with divers, who requested a minimum of 1 or 2 dives to see the fish during their stay in the Maldives (Z. Naseem & H. Hameez pers. comm.). At that time, large Napoleon wrasse (1.4–1.5 m TL) were resident at many popular dive sites (e.g. Banana Reef, Okkobe Thila, Nassimo Thila and Male' West Park area in Male' Atoll, Fish Head in North Ari Atoll, Rakeedhoo Kandu in Vaavu Atoll), perhaps attracted by the boiled eggs fed to them by dive guides (Z. Naseem, H. Hameez & H. Shareef pers. comm.). However, by the late 1990s, dive guides reported that large adults had disappeared from these sites (Z. Naseem, H. Hameez & H. Shareef pers. comm.).

Despite the ban, export of Napoleon wrasse continued for several years. For example, import figures for Hong Kong (which has a dedicated harmonized trade code for live fish in Hong Kong imports) — the major global trade hub for live reef fish for the luxury seafood trade, including the Napoleon wrasse — recorded imports of significant quantities of the species from the Maldives, at least until the late 1990s (Lau & Parry-Jones 1999). Although little information is available regarding catch and exports since 2000, exporters have occasionally been fined for attempting to export the species (e.g. Sun Online, 2012, title translated from Dhivehi to English: 'Company fined more that MVR 200,000 [around USD $13000 in today's market] for attempting to export Napoleon wrasse'; https://sun.mv/24092). There are also anecdotal reports that Napoleon wrasse are still being targeted by recreational sports fishers, according to social media postings from fishing charters (Table S1 in the Supplement at www.int-res.com/articles/suppl/n049p135_supp.pdf).

The only study to evaluate the abundance of this species in the Maldives occurred over 25 yr ago shortly after the 1995 ban was introduced. Underwater visual census surveys were conducted on Laamu Atoll from November 1996 to June 1997 at 5 different habitats (inner and outer reef slopes, channels, faros, and shallow reef or lagoon patches) (Sluka 2005). In the present study, we aim to understand the current status (density, sizes, presence of possible spawning aggregations) of the species on the same atoll and across the same habitats and whether the fishing ban has successfully safeguarded it there. We analysed Napoleon wrasse sighting data collected by trained observers from a tourism operator from across 50 sites spanning 27 consecutive months from January 2018 to March 2020. This study is important and relevant considering the species' value for dive tourism and its globally threatened status, as well as being an independent evaluation of the national conservation protection measure in place for the species. Results were considered against earlier studies in the Maldives (although direct comparisons were limited by methodological differences) and data from other countries.

2. MATERIALS AND METHODS

2.1. Survey method

Napoleon wrasse sightings were recorded during all SCUBA dives from the Six Senses Laamu Resort in Laamu Atoll, South-Central province of the Maldives, from January 2018 to March 2020 (27 consecutive months). The tourist resort conducts daily SCUBA dives, visiting more than 50 locations around Laamu Atoll. Dive site choices are determined by diver interest and capability, likelihood of sighting various fauna, environmental conditions, reef characteristics, and proximity to the resort. A protocol was developed to record marine megafauna sightings during these excursions, with Napoleon wrasse recorded by resort dive guides and researchers (collectively termed observers) who had completed training in recording Napoleon wrasse observations and were familiar with local reefs and ocean conditions. The species is considered well-suited to this kind of survey, being distinctive and readily observable, and it is relatively easy for trained observers to avoid double-counting individuals within the same dive (Sadovy de Mitcheson et al. 2019).

Trained observers travelled within regularly used, pre-defined areas (termed 'sites'), with date, location, start time, duration, maximum depth, estimated maximum horizontal visibility, name of observer, and number of Napoleon wrasse observed recorded immediately upon finishing each dive. From January 2019 onwards, the TL of the fish was also estimated as <1 m, ≥1 m, or of unknown size (in instances of poor visibility or if the dive guide did not have sufficient time to estimate the length of the fish). If multiple guides took the same route at the same site and time, the maximum number of Napoleon wrasse seen by a single observer was recorded. Sites dived at different times of the same day were treated as separate surveys. Guides were trained to avoid double-counting the same individual fish on each dive, and mostly took linear routes which helped to minimize this risk. If observers were distracted from observing a site effectively, for example, due to managing inexperienced divers, the dive was not included in the study to avoid inaccuracies or missed observations; thus, the numbers/abundances recorded should be considered as minima. While there is expected to be some error in the measurement of distances and body sizes, the same dive sites were regularly and consistently covered, and the size classes selected (<1 and ≥1 m) were coarse. Possible errors in such measurements were taken into account when interpreting data.

2.2. Analysis

Data were analysed if they included all the following parameters: location, date, duration, and water visibility. Only SCUBA dives longer than 30 min and conducted between 06:30 and 17:00 h were included due to the difficulty of observing fish during twilight conditions, giving sufficient time for observation and for any fish that had possibly been disturbed by the entry of divers to recover. For site and habitat-type analyses, only sites with a total survey time of more than 10 h or a total of 10 km travelled were included to ensure sufficient sample sizes (Sadovy de Mitcheson et al. 2019).

A total of 4 reef types (hereafter 'habitats') were identified (Sluka 2005): (1) channels: reef passes that lead from the inside to the outside of the atoll rim and into deeper water, including sites located on the corner of the channel; (2) inner reefs: reef slopes inside the atoll rim and abutting the lagoon; (3) outer reefs: reef slopes outside of the atoll rim but not including channel corners; and (4) faros: isolated submerged reefs on the inside of the atoll, incorporating shallow lagoonal reefs and surrounded by sand or areas with no cover.

2.2.1. Density by site and habitat type

Fish density (number of Napoleon wrasse observed ha^{-1}) was assessed by site and habitat type for the total duration of the 27 mo survey period. For each site, the area surveyed was calculated by multiplying the distance travelled (determined using GPS locations recorded on Google Earth, following the reef contour) by the maximum horizontal visibility for each survey, up to 25 m wide (i.e. swath width). The mean (±SD) swath width was 18.33 ± 4.8 m. Fish density was calculated by dividing the total number of fish observed by the area covered during each survey. Mean density and standard error were calculated for each site and habitat type.

To test for differences among habitat types and among sites within the same habitat type, a Tweedie distribution was adopted due to a zero-inflated and right-skewed distribution (Zhou et al. 2020). A generalised linear model (R package 'glmmTMB'; Magnusson et al. 2017) and post hoc analysis using Tukey method (package 'lsmeans') were used to identify pair-wise differences. A significance level of $\alpha = 0.05$ was used. Analysis was conducted in RStudio (v.2022.02.0).

Densities of Napoleon wrasse estimated to be ≥1 m in TL (large fish) were determined from January 2019 to March 2020 (15 mo) for each site and habitat type using the same method and analysis as above.

2.2.2. Evidence of aggregations by site

An increase in fish densities or numbers by a factor of at least 4 above that of the typical densities or numbers of fish observed are suggestive of possible spawning aggregations. However, to confirm that a temporary gathering is solely for the purpose of spawning, and not for any other purpose, it is necessary to witness spawning (Domeier 2012). For the Napoleon wrasse, since small individuals of the species occasionally travel in small groups which are not spawning aggregations (e.g. Sadovy et al. 2003), temporarily elevated densities alone would not be sufficient evidence of a possible spawning aggregation unless both large and small fish were seen together and/or spawning was observed; large males tend to be present with smaller females only when aggregating to spawn (Colin 2010). To avoid misclassifications of possible spawning aggregations due to occasional chance number increases, only sites with elevated densities of 4 or more occurring on at least 4 separate occasions and with the presence of at least one large individual (≥1 m TL) (minimum reported size for male Napoleon wrasse: 90 cm TL; Choat et al. 2006) were considered as candidates. Due to this condition, only surveys from January 2019 were included, as the size of fish was not recorded before this time. For all surveys fitting these criteria, minimum, maximum, and mean putative aggregation densities were calculated.

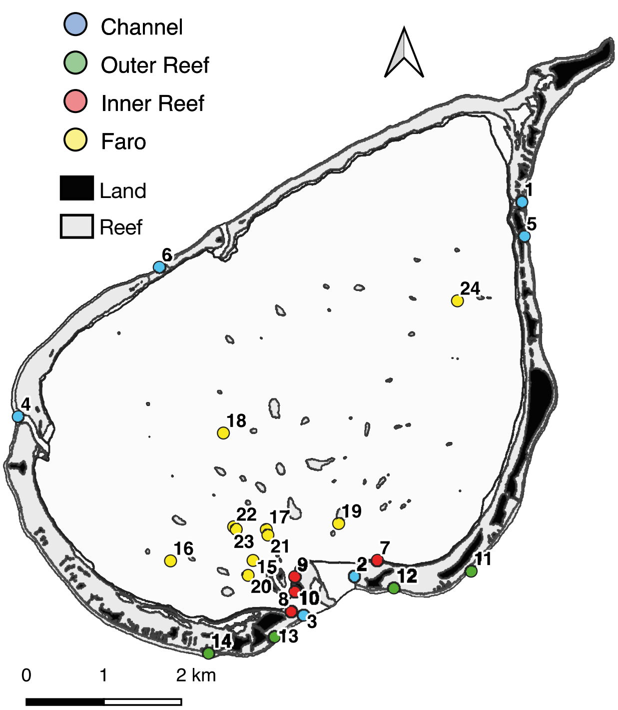

Fig. 1. Laamu Atoll, Southern Maldives, showing the 24 sites sampled for Napoleon wrasse *Cheilinus undulatus* density from January 2018 to March 2020. Colours of location points represent 4 reef habitat types

3. RESULTS

3.1. Survey distribution

A total of 24 sites were surveyed (6 channels, 4 inner reefs, 4 outer reefs, 10 faros) (Fig. 1) involving 2702 individual surveys, 2561.4 h of observation, and 1203.5 ha covered from January 2018 to March 2020. The mean (±SE) area covered per survey was 0.45 ± 0.004 ha (Table S2).

Per site, the mean survey frequency was 112.58 ± 24.12 and the mean survey duration was 106.73 ± 22.86 h (Table S2). The maximum depth of surveys ranged from 6–30 m (21 ± 0.1 m). Surveys took place between 06:30 and 16:34 h, with 75.13% (n = 2030) of surveys commencing in the morning and 24.87% (n = 672) in the afternoon. A total of 3211 sightings of Napoleon wrasse were made (Table S2).

3.2. Density by site and habitat type

A mean density of 3.08 ± 0.13 fish ha^{-1} was observed across all 4 habitats, covering a total of 1203.49 ha (Table S2). There was a significant difference in mean fish density among habitat types (z = 42.98, $p < 0.001$). The highest fish density was observed in channels (mean ± SE = 6.02 ± 0.34 fish ha^{-1}), significantly greater than in outer reefs (2.65 ± 0.20), inner reefs (2.29 ± 0.23), and faros (0.73 ± 0.08; Fig. 2). Faros had the lowest observed mean fish density, significantly less than all other habitat types.

The 4 sites with the highest mean fish densities were all channels, with Site 3 showing the highest density (7.08 ± 0.54) followed by Site 4 (6.54 ± 0.79) and Site 6 (5.61 ± 0.67) (Fig. 3; for site numbering associated with site location and names, see Fig. 1 and Table S2). However, a significant difference was found within channel reef habitats (z = 6.17, p <

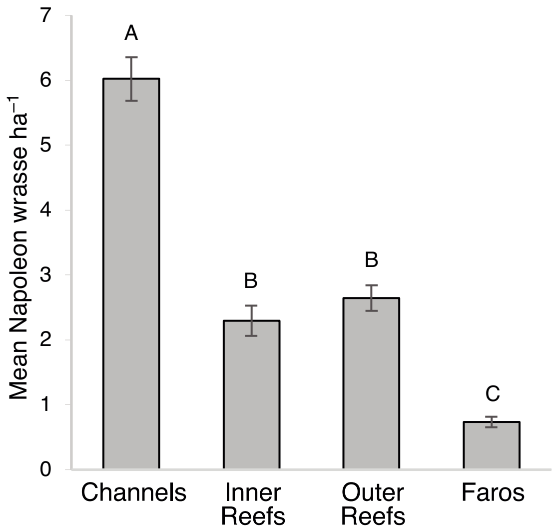

Fig. 2. Mean (±SE) Napoleon wrasse *Cheilinus undulatus* density at 4 different reef habitat types in Laamu Atoll, Southern Maldives. Paired letters indicate non-significant results (Tukey > 0.05). Note that highest channel densities are likely associated with an aggregation

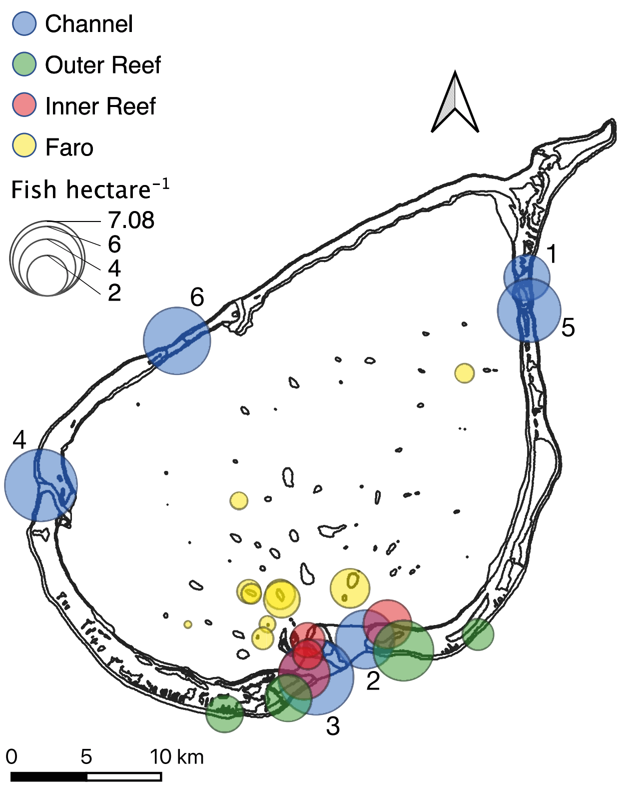

Fig. 3. Mean Napoleon wrasse *Cheilinus undulatus* density at 24 locations in Laamu Atoll, Southern Maldives. Data point size represents number of fish ha^{-1}; colour represents the 4 reef habitat types. Channel site numbers are labelled

0.001), with the aforementioned 3 sites showing significantly greater mean fish densities than the lowest density site (Site 1; 2.62 ± 0.34). Given the possible importance of some channels for aggregation behaviour, average channel density may sometimes be influenced by aggregation densities (i.e. increased over non-aggregation levels).

There were 904 observations of large fish (TL ≥ 1 m), with a mean density of 1.24 ± 0.07 large fish ha^{-1}. There was a significant difference in mean large fish density among habitat types ($z = -74.30$, $p < 0.001$), with channels showing significantly greater (2.48 ± 0.16) and faros showing significantly lower (0.20 ± 0.03) densities than all other habitat types (outer reefs: 0.917 ± 0.12; inner reefs: 0.923 ± 0.11) (Fig. 4). The 4 sites with the highest observed densities of large fish were all channel sites, with Site 3 showing the highest mean density (2.95 ± 0.26) followed by Site 6 (2.77 ± 0.38), Site 4 (2.75 ± 0.35), and Site 5 (1.79 ± 0.40) (Fig. 5).

3.3. Evidence of putative spawning aggregations by site and habitat type

Evidence of possible spawning aggregations — based on a factor of 4 times the non-aggregation density noted at survey sites on at least 4 occasions throughout the survey period, and with the presence of one or more large fish — was seen at 4 sites (chan-

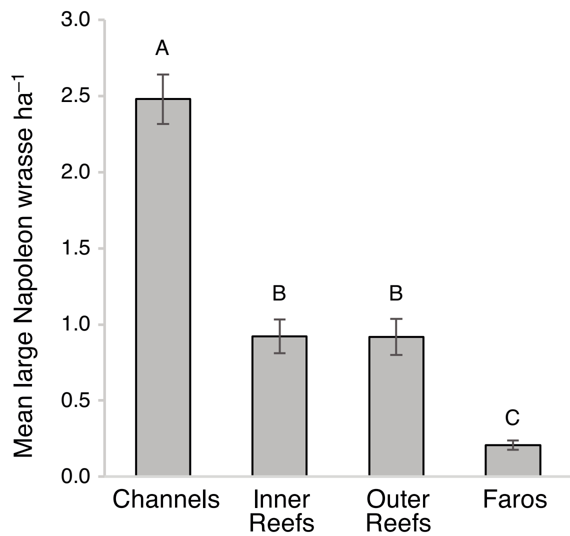

Fig. 4. Mean (±SE) large (>1 m total length) Napoleon wrasse *Cheilinus undulatus* density at 4 different reef habitat types in Laamu Atoll, Southern Maldives. Paired letters indicate non-significant results (Tukey > 0.05). Note that highest channel densities are likely associated with an aggregation

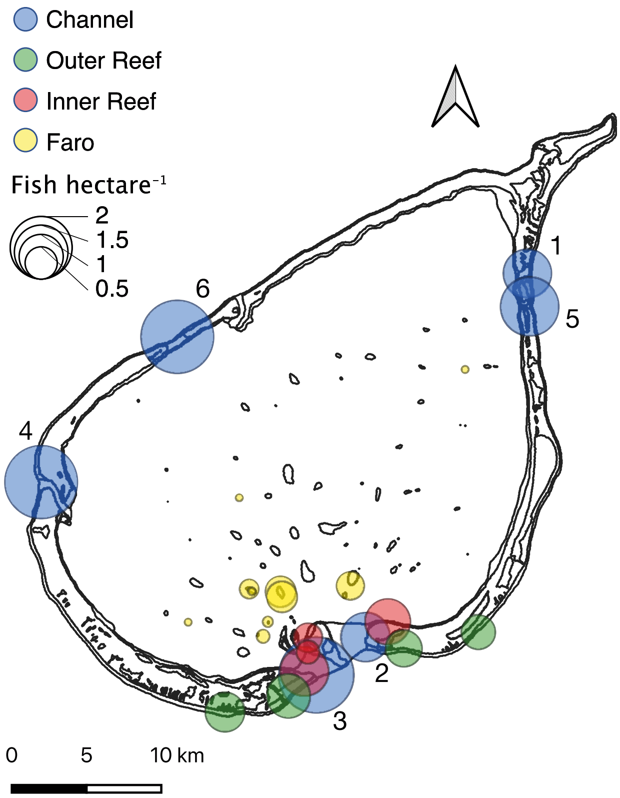

Fig. 5. Mean large (≥1 m total length) Napoleon wrasse *Cheilinus undulatus* density at 24 locations in Laamu Atoll, Southern Maldives. Data point size represents number of fish hectare^{-1}; colour represents the 4 reef habitat types. Channel site numbers are labelled

nel sites, n = 1; inner reef sites, n = 2; outer reef sites, n = 1). The largest mean putative aggregation densities were noted at Site 3 (46.81 ± 4.65), followed by Site 8 (20.63 ± 5.83), Site 7 (18.75 ± 1.99), and Site 13 (18.07 ± 5.49). Sites 3, 8, and 13 are adjacent to one another, and Site 7 is nearby. The maximum density for any single survey was 104.35 ha^{-1} recorded at Site 3, with 12 individuals observed, consisting of 11 smaller fish and one large individual. Aggregations consistent with described criteria were also recorded at 8 other locations, but these were observed on fewer than 4 occasions throughout the survey period (Table S3). These locations included Site 1, a channel site where footage captured a gathering of at least 11 fish, including large males (Fig. S1). Putative spawning aggregations occurred in all months of the year, although sampling effort was not sufficient to determine any lunar or seasonal pattern. However, since spawning was never observed, it was not possible to confirm if the aggregated behaviour was for the purpose of spawning.

4. DISCUSSION

4.1. Napoleon wrasse densities and sizes on Laamu Atoll

Observed Napoleon wrasse density was not uniform across the atoll and varied significantly among the 4 habitats considered. Channels exhibited significantly higher densities than all other reef habitat types, likely influenced by occasionally aggregated numbers, and the lowest densities were recorded around faros. Densities were not significantly different between outer and inner reefs. Mean densities varied by a factor of 8, from a high of 6.02 ha^{-1} in channels to a low of 0.74 ha^{-1} around faros.

It is possible that specific channels on Laamu Atoll may be more important than others for this species. A significant difference was found among channel sites, but only between channels with the highest and lowest densities. The differences could also be due to observing fish in aggregations by chance during surveys at one site and not the other. Site 3 was surveyed 4 times more than Site 1; the chances of missing an aggregation are high since if they form for spawning, they may only form briefly (Colin 2010).

Habitat patterns for Napoleon wrasse identified in this study are consistent with a previous study on Laamu Atoll in 1996–1997, where Napoleon wrasse were likewise reported to be most common in channels, followed by outer reefs. However, no Napoleon wrasse were observed in quantitative surveys in the inner atoll rim or faros (Sluka 2000). In a study conducted a few years later, the species was more common in channels than in other habitats surveyed, but again, no fish were found around faros. Sizes did not vary between outer- and inner-atoll rim sites and channels, with most fish being between 60 and 100 cm in length (Sluka 2005). Although densities in the 2 studies by Sluka (2000, 2005) are not directly comparable to the present study (due to the short survey periods and different measurement methods in the Sluka studies), some apparent similarities are suggested, such as the presence of large fish and the indication that channels are an important habitat for the species. Reports of large fish (>120–150 cm) in channels and groups of fish indicative of spawning aggregations in Sluka's (2005) study indicate that at that time, as presently, the status of the population on Laamu Atoll was a reflection of low or no fishing pressure. The current study likewise identified channels as important habitat for fish species. Elsewhere, reef channels, which provide transitions between productive shallow reefs and the open ocean, often host aggregations of a diversity of fish taxa and, although poorly recognized, can provide multiple social and ecological benefits for islands and their peoples (Fisher et al. 2018, Breckwoldt et al. 2022).

Relative to densities of Napoleon wrasse elsewhere in their broad global geographic distribution and within their preferred habitats (i.e. channels, deep-water slopes or drop-offs) and under low levels of known fishing pressure, numbers found in the channels of Laamu Atoll are medium to high and similar to unfished areas in other countries. This strongly suggests that the protection of this species in the Maldives has been effective in this atoll. Elsewhere, as in New Caledonia and French Polynesia, recorded natural (unfished) densities in favoured habitats like reef edges or channels rarely exceed 10 fish ha^{-1} and are more typically in the range 5–6 fish ha^{-1} (Sadovy et al. 2003, Russell 2004, Chateau & Wantiez 2007); this density compares favourably with the 6.02 ha^{-1} we recorded in the Laamu channels. Where the species is exploited in some other countries, densities are 10- to 100-fold less, the latter in particularly heavily fished areas (Sadovy et al. 2003, Russell 2004, Sadovy de Mitcheson et al. 2019). For example, in heavily fished locations across Indonesia, densities are <1 fish ha^{-1} and the fish is rare in surveyed and unprotected areas of the Philippines (Romero & Injani 2014, Sadovy de Mitcheson et al. 2019). Although densities may vary naturally across the range of the species, its abundance, the high numbers of large individuals, and the presence of putative spawning aggregations in Laamu Atoll indicate that Napoleon wrasse densities in this area are within the range of what could be considered an undisturbed population.

Since Napoleon wrasse are protogynous hermaphrodites and only individuals >90 cm TL are males, the presence of larger fish (i.e. males) as well as putative reproductive gatherings are good indicators of reproductive viability. Exploited populations tend to contain mainly smaller fish which may include few, if any, males; this can limit reproductive potential if females do not respond by changing sex at a smaller size. In heavily fished areas, most fish observed are within the juvenile size range (Choat et al. 2006, Colin 2010, Sadovy de Mitcheson et al. 2010, Graham et al. 2015). In the current study, fish size was recorded from January 2019 onwards, and 'large' fish (i.e. ≥1 m TL) were noted in the highest densities in channels and inner/outer reefs. The regular presence of large individuals along with temporally limited higher fish densities (as in channels) is indicative of spawning aggregation sites because adults gather briefly on a regular basis for mating but are otherwise mostly solitary (Sadovy et al. 2003, Chateau & Wantiez 2007, Colin 2010). Future monitoring should target lunar phases in order to investigate lunar or seasonal patterns surrounding these aggregations which may assist in management recommendations.

4.2. Management considerations

The Napoleon wrasse is a sedentary, pelagic, egg-producing reef fish that, once recruited onto the reef (i.e. post-settlement), is known to move linear distances on the order of 10 km (Green et al. 2015) but is unlikely to move between non-contiguous reefs separated by large distances of deep water (J. H. Choat pers. comm.). Hence, juveniles and adults within an atoll system are expected to remain there after settlement. However, the population is likely to be much more extensively distributed than within a single atoll due to the pelagic larval phase of the species, which allows for wide dispersal prior to settlement. Genetic analysis has shown no evidence of sub-structuring across much of the range of the species (Ma et al. 2019). Hence, protection and management of this threatened fish should ideally be considered at local, national, and regional scales. Given that adults are known to move distances along reefs of up to 14–16 km (Weng et al. 2015, Daly et al. 2020) to reach spawning sites, protection is needed at the level of atolls which, across multiple atolls, will collectively support national protective measures. For example, marine protected areas have successfully protected this species in the Philippines (Tubbataha Reefs Natural Park) and Indonesia (Bunaken MPA, Banda Island MPA), while prohibition of commercial exploitation and/or export has evidently maintained viable populations in Palau, Seychelles, New Caledonia, and Australia, amongst other countries (e.g. Sadovy de Mitcheson et al. 2019, Nañola et al. 2021, Oktaviani et al. 2021). Conversely, where the species is exploited and not effectively controlled, few adults remain and even juveniles can be rare. For example, a survey conducted almost 2 decades ago recorded just 5 individuals at one site and none at other sites along the west coast of India, while heavily exploited areas in Indonesia have few to no adult-sized fish (Sadovy et al. 2003, Sluka 2005, Sadovy de Mitcheson et al. 2019).

Studies to date, including the present study, indicate that reef (including atoll) channels are a preferred habitat for this and many other reef-associated species, and hence, these are important areas within reef ecosystems. Protection of such habitats is particularly important for Napoleon wrasse as well as other charismatic reef megafauna, including manta rays and sharks (Stevens & Froman 2019). The channels are also important for the spawning aggregations of many other species such as certain groupers (Epinephelidae) and snappers (Lutjanidae) (Sadovy de Mitcheson & Erisman 2012). Where dive tourism is an important economic activity, the preservation of these popular dive sites can be a key contribution to this sector.

The Maldivian Government has made several encouraging commitments within the last 5 yr to increase marine protection across the Maldives (The President's Office, Strategic Action Plan 2019–2023 https://presidency.gov.mv/SAP/). In December 2021, 7 new Marine Protected Areas on Laamu Atoll were designated, including Site 1, which is a channel. Fishery management plans specific to each site are expected to be finalised in 2023 and will determine what level of protection each site is given. We strongly recommend this area should be 'highly protected', which means limiting fishing to trolling only but only without methods that are known to take this species (such as 'poppers', which should be banned), to avoid the risk of catching Napoleon wrasse and other reef fish using other fishing methods. We also recommend the protection of Site 3 and adjacent sites (Sites 2, 7, 8, and 13), which collectively appear to be particularly important for Napoleon wrasse and host possible spawning aggregation sites for the species. In this area, we strongly recommend a total ban on all fishing because of its critical value as a spawning site for Napoleon wrasse and Serranidae (groupers). We also stress the importance of monitoring and enforcement of protected sites and recommend this is best achieved by working closely with communities. Finally, we encourage the study of this species on other atolls of the Maldives, with the precautionary protection of at least 30% of channel sites on all atolls of the Maldives to ensure the continued conservation of this vulnerable coral reef fish from exploitation (O'Leary et al, 2016, Woodley et al. 2019).

4.3. Non-specialist diver surveys and study constraints

This study demonstrates that monitoring protocols based on trained resort staff, especially dive guides, can be cost-effective and replicable and are well-suited for adoption by other tourist operators in the Maldives and elsewhere. This is especially the case if the target species are large, distinctive reef fish, many of which are vulnerable to increased fishing. Data collected in this way can help policymakers and others to make more informed decisions around coral reef management. Engaging non-specialist observers, such as trained dive guides, in the collection of these data can also be a powerful education tool that benefits both the guides and tourist divers participating in the dives. Although training was provided, inter-observer bias in fish counts may have occurred due to the inclusion of multiple observers (more than 30 individuals contributed throughout the survey period) with varying levels of experience. Smaller fish, being less remarkable and somewhat more secretive or wary than larger fish, may have been under-sampled. Findings from this study may not be representative of the whole of Laamu Atoll, as our survey effort was not uniform across all sites. Sites were initially selected due to the likelihood of providing a good dive experience — either sightings of various megafauna species (Napoleon wrasse being one of many species), for particularly attractive coral reefs, or for favourable environmental conditions for guest excursion. Site selection was also constrained by distance from the Six Senses Laamu Resort. Opportunities for expanding the number of sites surveyed in future will be undertaken whenever possible.

5. CONCLUSIONS

This is the first study in 25 yr — and the first comprehensive study of its kind — to evaluate the densities of Napoleon wrasse on Maldivian reefs. Our findings suggest that the implementation of a national fishing ban in 1995 has successfully conserved Napoleon wrasse on Laamu Atoll and that its population is currently in good condition. We come to this conclusion based on observations of a wide size range of animals, by comparison with natural densities elsewhere, and based on observations of dive guides over time. Results identified key habitats used by the species and potential spawning sites, and we discussed limitations and caveats to our study.

Our research highlights opportunities to work with the tourism sector, using trained observers to conduct underwater surveys on a distinctive species as a cost-effective tool for surveying a naturally uncommon, highly visible, charismatic, and threatened fish of interest to divers that would otherwise be costly to survey effectively. Based on our findings, we recommend the protection of Napoleon wrasse aggregation sites on Laamu Atoll, specifically Site 3 and adjacent sites (Sites 2, 7, 8, and 13), to conserve existing reproductively viable populations; however, confirmation that they are indeed spawning sites is needed through direct observation of spawning. Since the status of Napoleon wrasse populations within the other 25 geographical atolls in Maldives remains unknown, we recommend widespread collaboration between tour operators on other atolls to replicate our research and assess the status of this species in those areas. Such findings would help guide local atoll-based management interventions and contribute significantly to an improved understanding of Napoleon wrasse populations across the archipelago.

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