Protected areas and benthic characteristics influence the distribution of the Vulnerable bumphead parrotfish *Bolbometopon muricatum* in the Andaman and Nicobar Islands, India

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Abstract The Vulnerable bumphead parrotfish *Bolbometopon muricatum*, a highly prized fishery resource worldwide, has experienced population declines throughout its geographical range. There is limited knowledge of the distribution and abundance of, and threats to, this fish in Indian waters, particularly for the Andaman and Nicobar Islands. To assess the species' distribution and conservation status we conducted underwater surveys across 75 sites around 51 islands and interviewed 99 fishers across the Andaman and Nicobar archipelago. We recorded a total of 59 individual *B. muricatum* across nine sites from the northernmost island in the Andamans (Landfall Island) to the southernmost island in the Nicobars (Great Nicobar Island). Interviews revealed that most fishers (100% in Nicobar, 94% in Middle Andaman, 62% in South Andaman) had seen *B. muricatum*, and knowledge of the species is highest amongst spearfishers. Generalized linear models indicated that presence of marine protected areas and high live coral cover influenced the abundance and distribution of *B. muricatum*. The species' density seems to be naturally low in the archipelago. We discuss our findings in the light of protecting rare and threatened species, and recommend strengthening the existing marine protected areas in these islands.

Keywords Andaman and Nicobar Islands, *Bolbometopon muricatum*, bumphead parrotfish, coral reefs, India, marine protected area

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Introduction

Certain fish groups have important functional roles in structuring coral reef ecosystems, including corallivory (Cole et al., 2011), herbivory (Diaz-Pulido & McCook, 2003; Hughes et al., 2007; Burkepile & Hay, 2010) and piscivory (Jennings & Polunin, 1997; Boaden & Kingsford, 2015). Conservation of such fish groups is a key priority for ecosystem managers (Nyström, 2006; Bellwood et al., 2006). One such fish that is also of conservation concern is the bumphead parrotfish *Bolbometopon muricatum*, the largest herbivorous and corallivorous fish, categorized as Vulnerable on the IUCN Red List (Chan et al., 2012). An individual can consume up to 5 t of structural reef carbonate per year (Bellwood et al., 2003), and the species promotes coral growth and recruitment by balancing coral erosion and calcification, preventing macroalgal growth and maintaining sediment flow in the reef ecosystem (Bellwood et al., 2003, 2011; Kobayashi et al., 2011; McCauley et al., 2014; Roff et al., 2017).

A large body size, aggregating behavior and limited activity at night make *B. muricatum* an easy target for spearfishers (Bellwood et al., 2003; Donaldson & Dulvy, 2004; Kobayashi et al., 2011; Chan et al., 2012; Munoz et al., 2014; Hamilton et al., 2016). Combined with slow growth and low replacement rates, this has resulted in population declines across the Indo-Pacific and Red Sea (Kobayashi et al., 2011; Chan et al., 2012; Andrews et al., 2015). These declines have been particularly marked in the Solomon Islands, Papua New Guinea, Samoa, Guam, the Marshall Islands and parts of Malaysia and Fiji (Bellwood et al., 2003; Aswani & Hamilton, 2004; Dulvy & Polunin, 2004). Many countries have implemented conservation measures for the species, including establishment of marine protected areas and restrictions on spearfishing (Dulvy & Polunin, 2004; Weeks et al., 2017).

In India *B. muricatum* occurs from the Gulf of Mannar in Tamil Nadu state (Varghese et al., 2011), to the Lakshadweep archipelago (Rohan Arthur, pers. comm.) and the Andaman and Nicobar Islands (Rajan et al., 2013). Little is known about the species' distribution and conservation status around the Andaman and Nicobar Islands. In the recent past the islands have been affected by a series of coral bleaching events (in 1998, 2002, 2010 and 2016) and the Tsunami of 2004, which may have disturbed the species' habitat (Jeyabaskaran and Rao 2007; Patankar et al., 2012; Mondal et al., 2013).

For species that are rare, threatened or Data Deficient, local ecological knowledge has been used to examine population trends (Aswani & Hamilton, 2004; Lavides et al., 2009;

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Lavides et al., 2016; Pan et al., 2016). Studies that have combined ecological data from underwater surveys with information from fishers have shown that both sources can provide reliable information (Iniesta-Arandia et al., 2014; Zappes et al., 2014). In addition, the inclusion of local ecological knowledge in conservation research can increase the involvement of local stakeholders in conservation activities (Drew, 2005). We therefore used a combination of surveys and interviews to assess the abundance, distribution and conservation status of *B. muricatum* across the Andaman and Nicobar Islands. Using generalized linear models, we test whether abundance is influenced by a combination of benthic variables and the presence of marine protected areas, and discuss our findings in the light of developing conservation strategies for *B. muricatum* around these islands.

Study area

The Andaman and Nicobar archipelago of India is part of the Indo-Myanmar and Sundaland biodiversity hotspots in the south-eastern Bay of Bengal (Davidar et al., 1995; Roberts et al., 2002). The archipelago comprises 350 islands and a land area of 8,249 km^2, with a total coastline of 1,962 km. It includes the Andaman group ($>$ 325 islands, 24 inhabited, 6,408 km^2) and the Nicobar group (21 islands, 13 inhabited, 1,841 km^2), separated from each other by the Ten-degree Channel. The Andaman Islands have 105 protected areas (9 national parks and 96 wild sanctuaries), all of which encompass coast and surrounding waters, and the Nicobar Islands have seven community-protected marine areas, with restrictions on fishing and other resource use activities (Patankar et al., 2015). The islands are influenced by both the south-west and north-east monsoons (May–December).

Methods

We surveyed sites across the archipelago, to account for variability in coastal morphology, oceanographic conditions, geography and reef resources. In total we surveyed six sites at Camorta Island, four at Great Nicobar Island and Nancowry Island, two at Aves, Katchal, Little Nicobar, Interview, Twins, Cinque, Sister, Rutland and Eastern Reef islands, and one site at all other locations. The number of sites around each island were selected based on the size of the island, aspect, and location and accessibility of the reef (Fig. 1).

Density and abundance

At each site we estimated the abundance of *B. muricatum*, carrying out an underwater visual census at a total of 75 reef sites across 51 islands, using SCUBA diving, during November 2013–April 2015. At each site we counted *B. muricatum* along five random 50 × 10 m transects (500 m^2) delineated with a 50 m fiberglass tape. Identification of *B. muricatum* is relatively straightforward because of its large size and the presence of a unique bulbous bump on the head. On sighting, we counted the number of individuals and visually estimated their size. A prior calibration was conducted to refine the accuracy and precision of our underwater size estimates until they were within 10% of actual lengths.

Benthic cover

We quantified the benthic cover (live coral cover, turf algae, macroalgae, sand, rubble, soft coral and others) at each transect by photographing five 1 × 1 m quadrats, one at each 10 m along the 50 m transect, using an underwater camera without flash. Per cent benthic cover categories were measured using *Adobe Photoshop 7.0* (Adobe Systems, San Jose, USA).

Documentation of local knowledge

To investigate the awareness and perception of *B. muricatum* by fishers we conducted a total of 99 semi-structured interviews (Huntington, 2010) during January 2014–May 2015, in three villages in South Andaman (Wandoor, 38 interviews; Junglighat, 15; Mohanpura, 7), two villages in Mayabunder in Middle Andaman (17) and five villages in the Nicobars (Tapong, 4; Hitui, 4; Ramjav, 7; Masala Tapu, 4; Kakana, 3). These are the major fishing villages in the archipelago. All respondents were male, as fishing activities are predominantly carried out by men in this region. The number of interviews in each region was based on the intensity of fishing, the ethnic heterogeneity of the fishing community and the diversity of fishing gear used. Thus, there were 60 interviews in South Andaman, which has the highest number of fishing vessels, several ethnic groups (Telugu, Bengali, Malayali and Tamil) and a high diversity of fishing gear (gillnets, trawls, long lines, hook and lines, cast nets, and hand-held wooden spears and harpoons), and 17 in Middle Andaman and 22 in Central Nicobar, where spearfishing and hook-and-line are the common fishing methods used, by Karen and Nicobari communities. We used the snowball sampling method to select the interviewees in each village (Kvale, 1996). Interviews were conducted in Hindi in South Andaman, and in in Karen and Nicobari in the Middle Andaman and Nicobar Islands, respectively.

To minimize any potential bias, all interviews were carried out by VP, with help of a local interpreter in the Middle Andaman and Nicobar Islands. Most interviews lasted 10–20 minutes and were conducted at fishers' houses or at fish landing sites. The questions included personal data

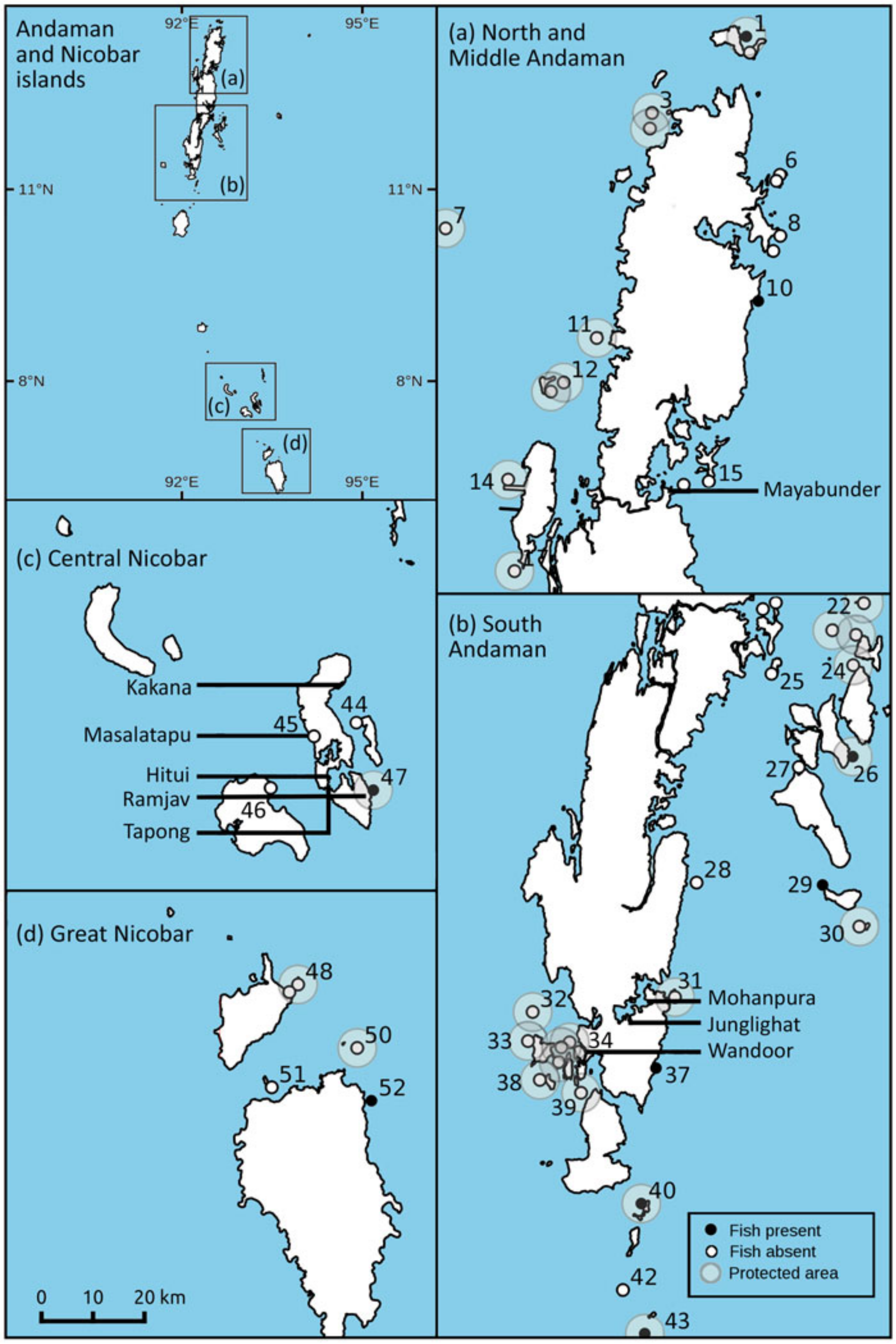

FIG. 1 Survey sites and the presence of the bumphead parrotfish *Bolbometopon muricatum* in the Andaman and Nicobar Islands. The islands/sites that were surveyed for *B. muricatum* status are: 1, Landfall; 2, East; 3, White cliff; 4, Reef; 5, Excelsior; 6, Delgarno; 7, West; 8, Ross and Smith; 9, Craggy; 10, Kwangtung; 11, Latouche; 12, North Reef; 13, Sound; 14, Aves; 15, Interview; 16, South Reef; 17, Long Island; 18, North Bay; 19, North Button; 20, Guitar; 21, Middle Button; 22, Outram; 23, Henry Lawrence; 24, Strait; 25, John Lawrence; 26, Havelock; 27, Eastern Reef; 28, Neil; 29, Sir Hugh Ross; 30, Ross; 31, Twins; 32, Tarmugli; 33, Grub; 34, Chester; 35, Malay; 36, Rutland; 37, Boat; 38, Jollybuoy; 39, Red Skin; 40, Cinque; 41, North Passage; 42, Sister; 43, Trinket; 44, Camorta; 45, Katchal; 46, Nancowry; 47, Menchal; 48, Great Nicobar; 49, Little Nicobar; 50, Cabra; 51, Kondul. The nine labelled locations are where the interviews were carried out.

about the respondents (island and village of residence, age, gender, level of education), preferred fishing gear, target and non-target species captured, and awareness of *B. muricatum*. In particular, the fishers were asked if they were aware of *B. muricatum* in their waters, and were shown photographs, to avoid erroneous results arising from the use of different local names for the same fish. We then asked fishers how many times they had seen the fish in the previous year, and how many times they had seen aggregations (i.e. > 25 individuals). When people provided information about their experience of catching *B. muricatum*, we requested descriptive details of the method of fishing, time of fishing (day/night) and where they fished. Interviews were recorded in writing and later transcribed for quantitative analysis. Before an interview, respondents were provided with information about the nature and expected goals of the study, complete confidentiality was assured, and interviews proceeded only with consent of the interviewee.

Data analysis

We used descriptive statistics to analyse interview data. *Bolbometopon muricatum* spends most of its time foraging on structural reef carbonate (Bellwood et al., 2003; Donaldson & Dulvy, 2004) and, as marine protected areas of sufficient size can protect such fish species (Sadovy 2005; Green et al., 2015), we expected higher abundances in protected areas with a high per cent of live coral cover. The number of sites without *B. muricatum* was high (66 of 75) and therefore we used zero-inflated Poisson generalized linear models (GLM) to model abundance. An exploratory analysis revealed that these models performed better than a GLM with Poisson error (Vuong test statistic = 2.04, $P < 0.05$). The zero-inflated Poisson GLM is a two-step process in which abundances are modelled as count variables with a Poisson distribution conditional on the probability that the values are non-zero (a binomial variable). As *B. muricatum* was encountered at only a few sites we did not include multiple variables in a single model, to avoid overfitting. We compared the effects of live coral, soft coral and others, turf algae, and with and without a marine protected area. If the zero abundances in the data can be attributed entirely to the species' biology, then the zero model should only contain a single intercept term. We used package *pscl 1.4.9* in *R 3.4* for regression analysis (R Development Core Team, 2016).

Results

Abundance and distribution

Around the 51 islands surveyed, we sighted a total of 59 individual *B. muricatum* at nine islands (seven in the Andamans and two in the Nicobars), with Sister Island in South Andaman having the highest abundance (29 individuals) and the largest shoal size (18 individuals), followed by Craggy Island in North Andaman (one shoal of 12 individuals), six individuals at Nancowry, four individuals each at Rutland and John Lawrence islands, and a single individual at Great Nicobar, Landfall, Cinque and Neil Islands. All the fish were > 50 cm except one subadult (< 50 cm) at Neil Island. We did not observe any juveniles. This could be because the habitat we sampled is not preferred by juvenile reef fish (Hamilton et al., 2017). The average density of *B. muricatum* was 0.0262 individuals per ha at the nine sites where we sighted the fish, and the density across the entire archipelago was 0.0032 individuals per ha.

Influence of benthic cover and protected areas

Rutland Island in South Andaman had the highest live coral cover (mean 52.5 ± SE 0.1%, 2 sites); the lowest was recorded at Excelsior (n = 1), Kwantung (n = 1) and Landfall (n = 1) Islands (mean 21 ± SE 0.1%). Thirty-one islands surveyed had an intermediate cover of live coral (29–41%). Algal cover was low at most sampled sites, with the highest at Smith Island (19%, n = 1) in North Andaman and lowest (1%) at Katchal, West, Redskin, Kondul and Menchal Islands. Zero-inflated Poisson regression models for the effects of benthic variables and presence/absence of a marine protected area on the abundance of *B. muricatum* showed that live coral cover was an important predictor and any additional effects of benthic variables on the zero inflation part of the model could not be identified. The effects of live coral and presence of a protected area were positive in all count models. The best model contained effects of live coral, rubble and sand and management variables (Table 3).

Fishers characteristics

Of the 99 male respondents 53% were ≤ 40 years of age and 47% > 40, and level of education was low (most respondents had not completed secondary education). All interviewees were full-time fishers, except in South Andaman where 33% were part-time fishers, with farming as their alternative livelihood. All fishers used more than one type of fishing gear, to diversify catch composition. Hook-and-line, hand-held wooden spears and harpoons and gillnets were the most common fishing methods. Amongst these, hook-and-line was the most commonly used fishing gear across regions, followed by gills nets, spears and harpoons. The characteristics of respondents are summarized in Table 1.

Awareness/knowledge of *B. muricatum*

Most fishers were aware of the presence of *B. muricatum* in their waters (see Table 2 for a summary of respones to all questions). Amongst these, all fishermen in Central Nicobar and Middle Andaman had seen aggregations of the fish. *Bolbometopon muricatum* was most commonly referred to as *tota macchi*, which translates to parrotfish in Hindi, the most widely spoken language in the archipelago. All respondents in Middle Andaman and Nicobar had seen *B. muricatum* feeding, whereas in South Andaman only 22% had seen feeding. All the interviewed fishers who were aware of the presence of the fish in their waters were also aware that *B. muricatum* is not legally protected in the Andaman and Nicobar Islands (Anon., 1992). Most fishers in the Nicobars (91%), all fishers in Middle Andaman, and 8% of fishers in South Andaman had hunted the fish in their lifetime, using hand-held wooden spears or harpoons, mostly in daylight. All fishers who had caught the fish in their lifetime reported that the catch was opportunistic rather than targeted.

Discussion

We carried out the first investigation of the distribution and abundance of the Vulnerable *B. muricatum* in the Andaman

TABLE 1 Detailed individual, social and fishing characteristics of fishers interviewed in the Andaman and Nicobar Islands (Fig. 1).

Characteristics		South Andaman	Middle Andaman	Central Nicobar
No. of fishers interviewed		60	17	22
Age (%)	< 30	7	29	14
	30–40	37	53	41
	41–50	40	0	27
	> 50	17	18	18
Education (%)	None	57	35	35
	Below 10th grade (15 years of age)	37	65	65
	Below 12th grade (18 years of age)	5	0	0
	Below 21 years of age	1	0	0
Full-time fisher (%)		67	100	100
Part-time fisher (%)		33	0	0
Mean no. of weeks spent at sea/year ± SD		3.55 ± 1.98	3.00 ± 1.11	4.09 ± 1.63
% of fishermen using gear	Gillnet	0	0	50
	Hook & line	100	100	100
	Harpoon/spear	13	100	68

TABLE 2 Awareness/knowledge of fishers regarding *Bolbometopon muricatum* in the Andaman and Nicobar Islands (responses, except for range of sightings, are per cent of respondents on each island).

Questions	Characteristics	South Andaman (%)	Middle Andaman (%)	Nicobar (%)
Are you aware of the presence of *B. muricatum* in your waters?	Yes	62	94	100
	No	38	6	0
If yes, is it protected under the Wildlife Protection Act of India?	Protected	0	0	0
	Not protected	62	94	100
Have you ever seen aggregations of *B. muricatum* (i.e. > 25 individuals)?	Yes	16	100	100
	No	84	0	0
On how many occasions have you seen aggregations in the past year?	not seen	35	13	36
	1–5	65	63	45
	6–10	0	6	14
	> 10	0	18	5
	Range	1–5	1–15	2–15
In your lifetime, have you seen *B. muricatum* feeding?	Yes	22	100	100
	No	78	0	0
In your lifetime, have you hunted *B. muricatum*?	Yes	8	100	91
	No	92	0	9
If yes, with which method and at what time (day/night)?	Spear (day)	33	94	77
	Spear (night)	0	6	18
	Harpoon (day)	67	0	5

and Nicobar archipelago, using both quantitative and qualitative approaches. The species occurs broadly, from the northernmost island in Andaman (Landfall Island) to the southernmost island in the Nicobars (Great Nicobar Island) and, except for fishers from South Andaman, most respondents were aware of the presence of this fish, its aggregation behavior and had seen it feeding. Although we sighted 59 individuals from nine islands, the fish occurs patchily, with most sightings from only two islands, and with an apparently naturally low density. The mean density we recorded (0.0032 per ha) is comparable to that observed on reefs of Malaysia (0.0042 per ha), Myanmar (0.0016 per ha) and Thailand (0.0004 per ha; Kobayashi et al., 2011). These densities are, however, markedly lower than those in other areas (Great Barrier Reef: 30 per ha; Solomon Islands: 0.3–4.2 per ha; Hamilton & Choat, 2012).

In areas where *B. muricatum* is a fishery resource, free diving spearfishers exclusively target nocturnal aggregations (Comeros-Raynal et al., 2012). However, in the Andaman and Nicobar Islands all fishers reported that catch was opportunistic rather than targeted. The main fishing gear used in the islands is hook-and-line and, other than spear or harpoon fishers, most do not encounter *B. muricatum* on their regular fishing trips.

We found that the presence of a protected area, live coral and algal cover significantly influenced the distribution and

TABLE 3 The three best zero-inflated Poisson regression models testing the effects of management status (presence of marine protected areas, MPA) and benthic variables on the abundance of *B. muricatum* in the Andaman and Nicobar Islands.

No.	Model*	Covariates	Parameter estimates (mean ± SE)	Model fit (Mc-Fadden's pseudo-R^2)	AICc
1	Count model	Intercept	−1.39 ± 0.95	0.14	149.95
		Presence of MPA	0.70 ± 0.34		
		Live coral	0.07 ± 0.01		
	Zero model	Intercept	0.98 ± 0.63		
		Rubble	0.07 ± 0.05		
		Sand	0.03 ± 0.05		
2	Count model	Intercept	−1.39 ± 0.95	0.13	148.20
		Presence of MPA	0.76 ± 0.34		
		Live coral	0.07 ± 0.01		
	Zero model	Intercept	1.26 ± 0.53		
		Rubble	0.07 ± 0.05		
3	Count model	Intercept	−1.47 ± 0.95	0.12	148.24
		Presence of MPA	0.77 ± 0.01		
		Live coral	0.07 ± 0.34		
	Zero model	Intercept	1.90 ± 0.36		

*Count model describes covariates for abundance data, and zero model describes covariates for sites with zero abundance.

abundance of *B. muricatum*. Although changes in the composition of these benthic characteristics as a result of disturbances could have negatively affected the abundance and distribution of this species in the Andaman and Nicobar Islands (Krishnan et al., 2011; Patankar et al., 2012), no baseline data are available. Marine protected areas in which fishing and other activities are restricted aid the conservation of fish stocks (Donaldson & Dulvy, 2004) and in the Andaman and Nicobar Islands the existing protected areas may be vital for the protection of *B. muricatum* and other fishes. Evidence of low abundance of *B. muricatum* on ocean reefs surrounded by deep waters, and traits such as limited dispersal and gregariousness, could also have influenced the distribution and abundance of this fish (Hamilton & Choat, 2012; Munoz et al., 2014).

The current potential threats to *B. muricatum* in the Andaman and Nicobar Islands include incidental catch by fishers and degradation of coral reef habitats. Protected area designations and threatened species legislation are effective only if social conditions also encourage self-regulation (Sawchuk et al., 2015). Although the present protected areas are supporting higher abundances of *B. muricatum*, fishing and benthic degradation could potentially result in future declines. We recommend extensive long-term population studies of *B. muricatum* in the archipelago, a regional Red List assessment for the species and inclusion in the Indian Wildlife (Protection) Act 1972. As reef fishery is growing, it will be necessary to implement regulations to avoid population declines, e.g. a ban on night fishing for *B. muricatum*. The latter would not compromise the livelihood of the fishing community as catch of *B. muricatum* is opportunistic. Considering the Vulnerable status of *B. muricatum* globally, the species could be a flagship for educational campaigns focusing on the importance of conserving similar functionally important fish groups and protecting the coral reefs of the islands.

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Author contributions Study design, data collection and writing: VP; assistance with writing and preparation of map: TW; data analysis: AM.

Conflicts of interest None.

Ethical standards Nicobarese are a Scheduled Tribe of India, and entry into the islands is regulated by the Andaman & Nicobar Islands Protection of Aboriginal Tribes Regulation 1956. We obtained the requisite Tribal Area Entry Permits, to land and conduct research, from the Department of Tribal Welfare and District Commissioner's office at Port Blair. During each visit we also obtained permission to conduct research from the Chief Captain of the village and Chairperson of the Tribal Council of the area. We obtained all requisite clearances from the Nature Conservation Foundation's Institutional ethical committee and from the doctoral research committee of Marurai Kamaraj University prior to conducting fieldwork.

References

Andrews, A.H., Choat, J.H., Hamilton, R.J. & DeMartini, E.E. (2015) Refined bomb radiocarbon dating of two iconic fishes of the Great Barrier Reef. *Marine and Freshwater Research*, 66, 305–316.

Anon. (1992) *The Wildlife (Protection) Act, 1972*. Natraj Publishers, Dehradun, India.

Aswani, S. & Hamilton, R.J. (2004) Integrating indigenous ecological knowledge and customary sea tenure with marine and social science for conservation of bumphead parrotfish (*Bolbometopon muricatum*) in the Roviana Lagoon, Solomon Islands. *Environmental Conservation*, 31, 69–83.

Bellwood, D.R., Hoey, A.S. & Choat, J.H. (2003) Limited functional redundancy in high diversity systems: resilience and ecosystem function on coral reefs. *Ecology Letters*, 6, 281–285.

Bellwood, D.R., Hoey, A.S. & Hughes, T.P. (2011) Human activity selectively impacts the ecosystem roles of parrotfishes on coral reefs. *Proceedings of the Royal Society B*, 279, 1621–1629.

Bellwood, D.R., Hughes, T.P. & Hoey, A.S. (2006) Sleeping functional group drives coral-reef recovery. *Current Biology*, 16, 2434–2439.

Boaden, A.E. & Kingsford, M.J. (2015) Predators drive community structure in coral reef fish assemblages. *Ecosphere*, 6, 1–33.

Burkepile, D.E. & Hay, M.E. (2010) Impact of herbivore identity on algal succession and coral growth on a Caribbean reef. *PLOS ONE*, 5, e8963.

Chan, T., Sadovy, Y. & Donaldson, T. (2012) *Bulbometopon muricatum*. In *IUCN Red List of Threatened Species 2012: e. T63571A17894276*. Http://dx.doi.org/10.2305/IUCN.UK.2012.RLTS.T63571A17894276.en [accessed 27 June 2018].

Cole, A.J., Lawton, R.J., Pratchett, M.S. & Wilson, S.K. (2011) Chronic coral consumption by butterflyfishes. *Coral Reefs*, 30, 85–93.

Comeros-Raynal, M.T., Choat, J.H., Polidoro, B.A., Clements, K.D., Abesamis, R., Craig, M.T. et al. (2012) The likelihood of extinction of iconic and dominant herbivores and detritivores of coral reefs: the parrotfishes and surgeonfishes. *PLOS ONE* 7, e39825.

Davidar, P., Devy, S., Yoganand, T.R.K. & Ganesh, T.P. (1995) Reserve size and implications for the conservation of biodiversity in the Andaman Islands. In *Measuring & monitoring biodiversity in tropical and temperate forests*. (eds T.J.B. Boyle & B. Boontawee), pp. 287–301. Centre for International Forest Research, Jakatra, Indonesia.

Diaz-Pulido, G. & McCook, L.J. (2003) Relative roles of herbivory and nutrients in the recruitment of coral reef seaweeds. *Ecology*, 84, 2026–2033.

Donaldson, T.J. & Dulvy, N.K. (2004) Threatened fishes of the world: *Bolbometopon muricatum* (Valenciennes 1840) (Scaridae). *Environmental Biology of Fishes*, 70, 373.

Drew, J.A. (2005) Use of traditional ecological knowledge in marine conservation. *Conservation Biology*, 19, 1286–1293.

Dulvy, N.K. & Polunin, N.V.C. (2004) Using informal knowledge to infer human-induced rarity of a conspicuous reef fish. *Animal Conservation*, 7, 365–374.

Green, A.L., Maypa, A.P., Almany, G.R., Rhodes, K.L., Weeks, R., Abesamis, R.A. et al. (2015) Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews*, 90, 1215–1247.

Hamilton, R.J., Almany, G.R., Brown, C.J., Pita, J., Peterson, N.A. & Howard Choat, J. (2017) Logging degrades nursery habitat for an iconic coral reef fish. *Biological Conservation*, 210, 273–280.

Hamilton, R.J., Almany, G.R., Stevens, D., Bode, M., Pita, J., Peterson, N.A. & Choat, J.H. (2016) Hyperstability masks declines in bumphead parrofish *Bolbometopon muricatum* populations. *Coral Reefs*, 35, 751–763.

Hamilton, R.J. & Choat, J. H. (2012) Bumphead parrotfish *Bolbometopon muricatum*. In *Reef Fish Spawning Aggregations: Biology, Research and Management, Fish & Fisheries Series, Vol. 35* (eds Y. Sadovy de Mitchson & P. L. Colin), pp. 490–496. Springer, Dordrecht, Netherlands.

Hughes, T.P., Rodrigues, M.J., Bellwood, D.R., Ceccarelli, D., Hoegh-guldberg, O., McCook, L. et al. (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology*, 17, 360–365.

Huntington, H.P. (2010) Using traditional ecological knowledge in science: methods and applications. *Ecological Applications*, 10, 1270–1274.

IUCN (2015) *The IUCN Red List of Threatened Species Version 2015-4*. Http://www.iucnredlist.org [accessed 19 November 2015].

Iniesta-Arandia, I., del Amo, D.C., Garcia-Neto, A.P., Pineiro, C., Montes, C. & Martin-Lopez, B. (2014) Factors influencing local ecological knowledge maintenance in Mediterranean watersheds: insights for environmental policies. *Ambio*, 44, 284–296.

Jennings, S. & Polunin, N.V.C. (1997) Impacts of predator depletion by fishing on the biomass and diversity of non-target reef fish communities. *Coral Reefs*, 16, 71–82.

Jeyabaskaran, R. & Rao, D. (2007) Impact of the December 24, 2004 tsunami on coral reefs of the Andaman and Nicobar Islands, India. *Reef Encounter*, 34, 25–30.

Kobayashi, D., Friedlander, A., Grimes, C., Nichols, R. & Zgliczynski, B. (2011) *Bumphead Parrotfish (*Bolbometopon muricatum*) Status Review*. NOAA Technical Memorandum, NOAA-TM-NMFS-PIFSC-26. U.S. Department of Commerce, Honolulu, USA.

Krishnan, P., Dam Roy, S., George, G., Srivastava, R.C., Anand, A., Murugesan, S. et al. (2011) Elevated sea surface temperature during May 2010 induces mass bleaching of corals in the Andaman. *Current Science*, 100, 1–117.

Kvale, S. (1996) *Interviews: An Introduction to Qualitative Research Interviewing*. Sage, London, UK.

Lavides, M.N., Molina, E.P.V., de la Rosa, G.E., Mill, A.C., Rushton, S.P., Stead, S.M. & Polunin, N.V.C. (2016) Patterns of coral-reef finfish species disappearances inferred from fishers' knowledge in global epicentre of marine shorefish diversity. *PLOS ONE*, 11, e0155752.

Lavides, M.N., Polunin, N.V.C., Stead, S.M., Tabaranza, D.G., Comeros, M.T. & Dongallo, J.R. (2009) Finfish disappearances around Bohol, Philippines inferred from traditional ecological knowledge. *Environmental Conservation*, 36, 235–244.

Mccauley, D.J., Young, H.S., Guevara, R., Williams, G.J., Power, E.A., Dunbar, R.B. et al. (2014) Positive and negative effects of a threatened parrotfish on reef ecosystems. *Conservation Biology*, 28, 1312–1321.

Mondal, T., Raghunathan, C. & Venkataraman, K. (2013) Coral bleaching in Andaman Sea—an indicator for climate change in Andaman and Nicobar Islands. *Indian Journal of Geo-Marine Sciences*, 43, 1945–1948.

Munoz, R.C., Zgliczynski, B.J., Teer, B.Z. & Laughlin, J.L. (2014) Spawning aggregation behaviour and reproductive ecology of the giant bumphead parrotfish *Bolbometopon muricatum* in a remote marine reserve. *PeerJ*, 2, e681.

Nyström, M. (2006) Redundancy and response diversity of functional groups: implications for the resilience of coral reefs. *Ambio*, 35, 30–35.

Pan, Y., Wei, G., Cunningham, A.A., Li, S., Chen, S., Milner-Gulland, E.J. & Turvey, S.T. (2016). Using local ecological knowledge to assess the status of the critically endangered chinese giant salamander *Andrias davidianus* in Guizhou Province, China. *Oryx*, 50, 257–264.

Patankar, V., D'Souza, E., Alcoverro, T. & Arthur, R. (2015) Erosion of traditional marine management systems in the face of disturbances in the Nicobar Archipelago. *Human Ecology*, 43, 697–707.

Patankar, V., D'Souza, E., Kumaraguru, A.K. & Arthur, R. (2012) Distance-related thresholds and influence of the 2004 tsunami on damage and recovery patters of coral reefs in the Nicobar Islands. *Current Science*, 102, 1199–1025.

Rajan, P.T., Sreeraj, C.R. & Immanuel, T. (2013) Fishes of the Andaman and Nicobar Islands: a checklist. *Journal of the Andaman Science Association*, 18, 47–87.

R Development Core Team (2016) *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Roberts, C.M., McClean, C.J., Veron, J.E., Hawkins, J.P., Allen, G.R., McAllister, D.E. et al. (2002) Marine biodiversity hotspots and conservation priorities for tropical reefs. *Science*, 295, 1280–1284.

Roff, G., Doropoulos, C., Mereb, G. & Mumby, P.J. (2017) Mass spawning aggregation of the giant bumphead parrotfish *Bolbometopon muricatum*. *Journal of Fish Biology*, 91, 354–361.

Sadovy, Y (2005) Trouble on the reef: the imperative for managing vulnerable and valuable fisheries. *Fish and Fisheries*, 6, 167–85.

Sawchuk, J.H., Beaudreau, A.H., Tonnes, D. & Fluharty, D. (2015) Using stakeholder engagement to inform endangered species management and improve conservation. *Marine Pollution*, 54, 98–107.

Varghese, M., Manisseri, M.K., Ramamurthy, M., Geetha, P.M., Thomas, V.J. & Gandhi, A. (2011) Coral reef fishes of Gulf of Mannar, S.E of India. *Fishing Chimes*, 31, 38–40.

Weeks, R., Green, A. L., Joseph, E., Peterson, N. & Terk, E. (2017) Using reef fish movement to inform marine reserve design. *Journal of Applied Ecology*, 54, 145–152.

Zappes, C.A., Gatts, C.E.N., Lodi, L.F., Simões-Lopes, P.C., Laporta, P., Andriolo, A. & Di Beneditto, A.P.M. (2014) Comparison of local knowledge about the bottlenose dolphin (*Tursiops truncatus* Montagu, 1821) in the south-west Atlantic Ocean: new research needed to develop conservation management strategies. *Oceans and Coastal Management*, 98, 120–129.