

**Coral damage by recreational diving activities in a Marine Protected Area of India:
Unaccountability leading to ‘Tragedy of the not so commons.’**

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Abstract

Globally, coral reefs have drastically declined due to local and global environmental stressors. Concurrently, coral reef tourism is rapidly growing in developing economies, which is one of many anthropogenic stressors impacting reefs. At the Malvan Marine Sanctuary, a Marine Protected Area (MPA) on the West coast of India, we investigate the impact of recreational diving on the reef from 2016 to 2019. To evaluate the diver's underwater behavior, a novel approach was used, wherein the video-log broadcasting website www.youtube.com was used. Evidential proof substantiates heavy physical damage to corals because of recreational diving activity, which may lead to the collapse of coral habitat if it continues unabated. This resource depletion ironically elevates the economy of dependents averting consequences due to lost corals, thus making this a ‘tragedy’ for corals which are not meant to be ‘commons’. The study asserts need for proactive conservation efforts with stringent implementation and restoration initiatives in this MPA.

Keywords: Marine Protected Area; Diving tourism; Reef degradation; Carrying capacity; Conservation.

Introduction

The sheer diversity, complexity, and flamboyant nature of organisms in coral reef habitat fascinate and attract millions of tourists and explorers to visit this fragile ecosystem. Coral reef tourism is one of the rapidly expanding business domains, worth US\$35.8 billion dollars per year, attracting around 70 million tourists globally, shaping and transforming the local economy, even an entire nation (Lamb et al., 2014; Spalding et al., 2017). In Southeast Asia and the Caribbean region, coral reef ecotourism has gained popularity while supporting the local economy and generating employment (Brander et al., 2007; De Groot et al., 2012; Sarkis et al., 2013).

Nonetheless, there is growing recognition that unmanaged and intensified recreational use of coral reef often results in environmental degradation, coral skeletal breakage, and tissue abrasion due to physical contact with tourists and boats (Flynn and Forrester, 2019; Giglio et al., 2020; Guzner et al., 2010; Hawkins et al., 1999; Terrón-Sigler et al., 2016). It has been noted that the physically damaged corals are more vulnerable to diseases, increased predation, poses disadvantage in space competition, and eventually leading to coral mortality (Giglio et al., 2020; Guzner et al., 2010; Lamb et al., 2014), illustrated in Fig. 1. Since the last four decades, numerous studies revealed that worldwide recreational activities mediated reef damage poses significant concern to coral reef managers and conservators (Woodland and Hooper, 1977; Kay and Liddle, 1989; Hawkins and Roberts, 1993; Medio et al., 1997; Hawkins et al., 1999; Jameson et al., 1999; Hasler and Ott, 2008; Chung et al., 2013; Lamb et al., 2014; Roche et al., 2016). Most often, the pressure of unrestricted dive tourism in poorly managed reefs in the tropical developing nations hinders conservation priorities (de Groot and Bush, 2010; Lamb et al., 2014). Further, hampering the coral growth rate, competitive success, susceptibility to thermal anomalies, and bleaching recovery (Carilli et al., 2010; Lamb et al., 2014; Roche et al., 2016).

It is a known fact that most of the Indian coral reefs are under severe stress due to anthropogenic pressure and climate change (De et al., 2017; Majumdar et al., 2018; Nanajkar et al., 2019). Massive tourist inflow and recreational diving induced coral damage have been reported from Andaman and Nicobar Island, Lakshadweep, and Gulf of Mannar (George and Jasmin, 2015; Turner et al., 2009; Venkataraman et al., 2012; Majumdar et al., 2018). Therefore, it is imperative to assess the impact of dive tourism on coral reef health to assist in reef management strategies and conservation policies in developing countries like India.

Densely populated coastal regions in the developing country often ensue a sense of intensified social interaction where natural resource supply is short, and demand is more. In such cases, resource over-

exploitation takes place due to competition rather than resource utility. We analyzed this socio-environmental interface in a marine protected area on the West coast of India, where a newly discovered profession of recreational dive tourism has triggered a situation that preliminarily depicts the classical case of ‘*Tragedy of the commons*’ (Hardin, 1968),but desolately reveals more deleterious consequence when we investigate qualitative socio-economy. The present study aimed to investigate the diving impact on coral health at the MPA while considering the socio-behavioral approach of tourists and local stakeholders pertaining to recreational diving. For the first time, this study evaluates video logs in the public domain providingvisual proof for our inferences. These aspects were analyzed further from the perspective of the ‘public goods’ game and resource sustainability perspective.

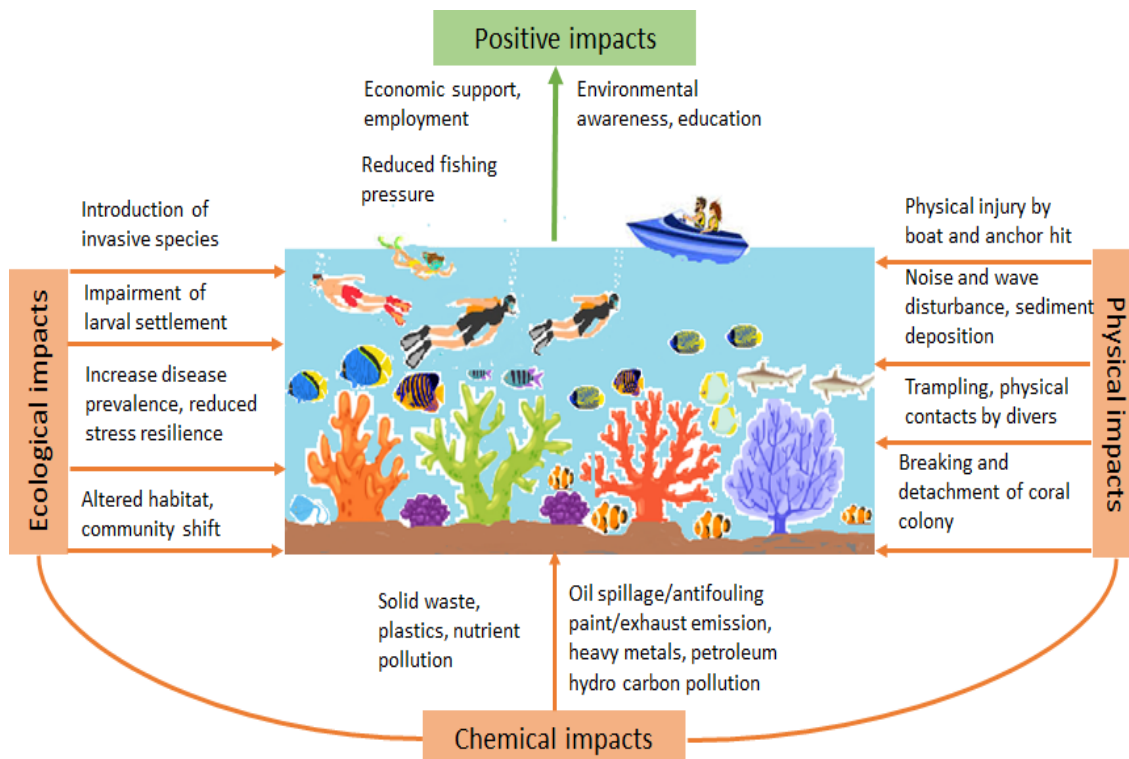


Fig. 1.Graphical representation of potential impacts of recreational activities includes SCUBA diving, snorkeling, boating on the coral reef habitat.

Methodology

Study area

The Malvan Marine Sanctuary, located on the Central West Coast of India,spreads over 29.122 km² area. Recreational and diving activities were restricted from October to May each year due to fair weather conditions. According to month-wise tourist arrivals in Malvan, December and January are the peak months for foreign and domestic tourists’ influx. Tourist footfall in the Sindhudurg district

is estimated to 200,000 in 2001-2002 and projected to be 641,427 in 2021-22, mostly visiting Malvan, with an overall annual increase of 6.00% (Munjaj, 2019). Local coastal communities, who were earlier involved in fishing, are now involved in tourism business (around 3000), the estimated annual revenue from tourism is about \$2.5 million (UNDP, 2011).

Four patch reef sites (T1, T2, T3, and T4) were selected for the present study, based on daily recreational diving and snorkeling activities. Two reef sites (T2, and T3) were chosen near the famous Sindhudurg Island (Sindhudurg fort), where most of the tourists were taken for SCUBA activity by the local diving operators, designated as the high diving intensity (HDI) sites and another two patch reef sites (T1, and T4) were selected about one Kilometer away from the intensive diving and snorkeling sites, where diving activity is low due to wave action and more depth, designated as low diving intensity (LDI) sites. The study site T2 and T3 (depth 2-4m) are located on the leeward side of the Sindhudurg Island (50-100m away from the shore) and subjected to massive tourist influx. Whereas T1 is located on the Southern side of the Island (~1km away) offshore, T4 is situated ~2km north of the Island (Fig. 2).

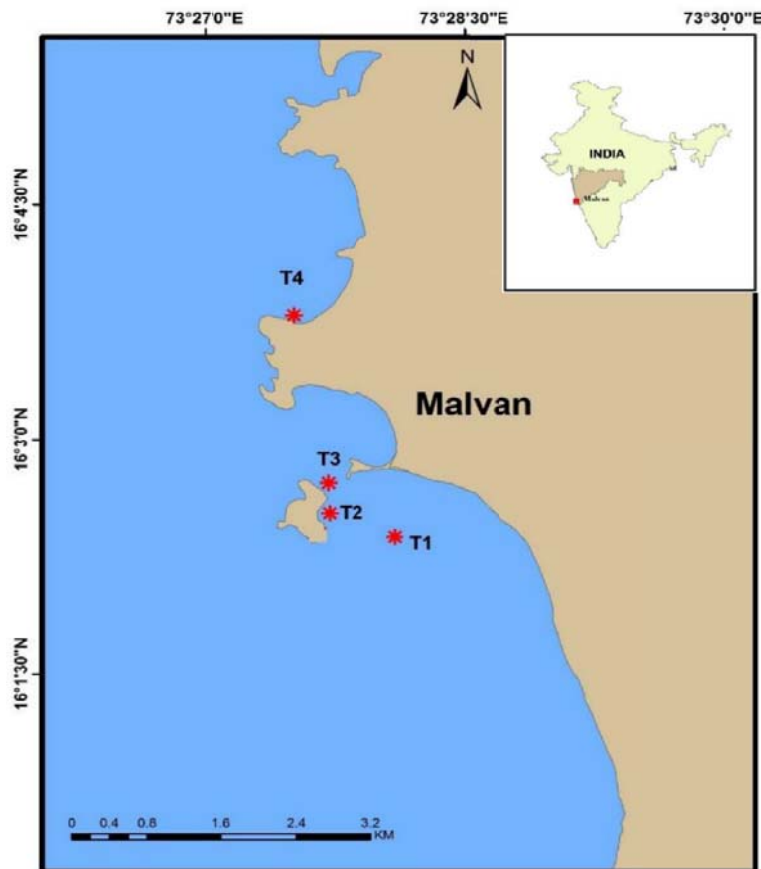


Fig. 2. Locations of the study sites with permanent transect locations. T1 is a non-diving site; T2 and T3 are high-intensity diving site (HDI); T4 is a low-intensity diving site (LDI).

Table 1. Location and characteristics of underwater survey sites in the MPA.

Site	Type of substratum	Geographical positions		Water Depths (m) at High tide	Characteristic of the study site
		Latitude (⁰ N)	Longitude (⁰ E)		
1	Patch coral reef, rocky & sandy bottom substrate	16 ⁰ 02'24.3"	73 ⁰ 28'13.8"	8-10	Non-dive site
2	Patch coral reef and rocky bottom substratum	16 ⁰ 02'31.5"	73 ⁰ 27'43.4"	2-4	High-intensity diving site (HDI)
3	Patch coral reef and rocky bottom substrate	16 ⁰ 03'786.4"	73 ⁰ 27'725"	2-4	High-intensity diving site (HDI)
4	Patch reef formation and rocky bottom substrate	16 ⁰ 03'84"	73 ⁰ 27'43.3"	7-9	Low-intensity diving site (LDI)

Coral reef survey

During a pilot study on coral bleaching in 2016, we observed numerous physically damaged corals. To investigate the reason for the coral physical damage in the MPA, we conducted subsequent underwater surveys at four reef sites (T1-T4, Fig. 2) during May 2016 aftermath of mass coral bleaching events. The following field surveys were carried out in the fair-weather months of May 2017, October 2018, and April 2019, consecutively. During each survey, three replicate belt transects (20m X 2m) were placed at each site of the sub-tidal reef by two divers (total 12 transects at four sites each year), and transects were laid approximately 10m away from each other. Each belt transect covered 40m² area and a total of 120m² area per survey site. GPS locations of the sites and coordinates of the transect endpoint were recorded using a handheld GPS device. The next consecutive annual surveys were conducted following the same GPS coordinates to monitor the same patch reefs. Assessment of coral damage by tourism activity was designed based on Lamb et al. (2014). Headcount of all the live coral colonies and physically damaged colonies were carried out along each transect. The number of physically damaged colonies (breakage, abrasion, tissue damage, and up-rooted coral colony) were counted to estimate the prevalence of impact by tourist activities (percent coral colonies per transect with visible physical damage).

Observation of diver's behavior

In the absence of long-term ecological datasets on the impact of SCUBA diving in the MPA, we considered unconventional data sources such as underwater video logs uploaded on the open-access video-sharing platform www.youtube.com by dive operators and individual tourists for analysis of the divers' and dive operators behavior and attitude towards the marine life during diving. In recent years, the application of YouTube videos in terrestrial wildlife conservation studies is relatively new (Harrington et al., 2019; Rebolo-Ifrán et al., 2019). However, the use of YouTube videos to study the health status of coral reef and tourism impacts is novel. To navigate relevant videos of the MPA, preliminary search of videos was carried out by using English language search keywords, e.g., `tourism+travel+SCUBA+diving+snorkel+coral+reef+underwater+Sindhudurg+Malvan+Tarkarli+Devbag+cheivla+sarjekote`. Videos qualified the preliminary search categories, were further scrutinized for confirming the locations (in this case MPA) by carefully observing the surroundings like landmarks, Sindhudurg Island (Fort), bottom substrate, coral and fish species assemblage, boat name, number, and local language. Only original videos were considered for this study, and redundant posting were dropped. All the videos were downloaded and analyzed in October 2019.

Quantification of divers and snorkelers

An estimate of annual SCUBA divers and snorkelers' at each diving site in the MPA was carried out following Jameson et al. (1999), wherein authors conducted 2-3 days long limited monitoring at each diving site. Whereas in the present study, an observation was conducted for four days employing a similar methodology (Table 2). To estimate the annual number of SCUBA divers or diver per year (DPY), and snorkelers per year (SPY) at each diving study site, daily headcount of SCUBA divers and snorkelers were conducted during 6-7 October 2018, and 16-18 April 2019 between 09:00 AM to 16:00 PM. DPY and SPY also include the number of diving crew underwater. The number of tourist boats and anchors used on the reef were also counted at the diving sites. To avoid the bias in tourist footfall numbers between working days and weekend holidays, in 2018, the survey was conducted on weekends, and in 2019, the survey was conducted during weekdays.

Data analysis

All the coral colonies were counted on each transect. The prevalence of physically damaged coral colonies was calculated by dividing the number of impacted colonies (damaged) at each transect with the total number of colonies at that transect and expressed as a percentage. At each location, three transects ($n=3$) were averaged and mean values were considered for analysis. Further, the Coral Damage Index (CDI) was calculated at each diving site, following the methodology of Jameson et al.

(1999), i.e., crucial cutoff value of 4% was considered for broken and damaged coral colonies. All data are reported as means \pm standard error (SE).

For analysis of SCUBA drivers' underwater behavior, we found a total of 126 video logs on the broadcasting website- YouTube. Videos were analyzed for three categories; 1) divers' body contact (touching/holding corals to control buoyancy and due to fin movement); 2) feeding of reef fishes, and 3) chasing of reef fishes.

Assessment of the number of tourist boats, anchors, divers, and snorkelers was calculated based on the daily observation data at the diving sites. DPY and SPY were estimated by multiplying the mean of the divers and snorkelers with the total number of SCUBA operation days (approximately 240 days) in a year.

The mean percentage data were normalized by arcsine square-root transformation. The impact of diving and snorkeling on coral physical damage was analyzed by one-factor and two-factor analysis of variance (ANOVA). Pearson correlation was calculated by conducting a paired two-sample Student's t-test with $\alpha = 0.05$ to detect correlation between coral physical damage and the annual mean diver and snorkeler numbers.

Result

Prevalence of physical injury on corals

The prevalence of physical injury includes breakage and abrasion of coral colonies were more prevalent at HDI sites compared to LDI sites throughout the study period. An increasing annual trend in mean coral physical injury was observed at the HDI sites. Mean physical injury in 2016 was recorded $8.19\% \pm 0.59\text{SE}$ at the HDI sites, which increased to $13.75\% \pm 2.16\text{SE}$ in 2017. Damaged colonies rose to $15.06\% \pm 1.6\text{SE}$ in 2018. During our survey in 2019, damaged coral colonies recorded to be $19.79\% \pm 0.94\text{SE}$. Relative coral physical injuries at LDI sites, were also found to be increased, accounted to $1.47\% \pm 0.05\text{SE}$ during 2016. In 2017, physically injured colonies recorded to be $1.69\% \pm 0.01\text{SE}$. Whereas, in 2018 and 2019, coral damaged accounted to be $2.83\% \pm 0.48\text{SE}$, and $3.36 \pm 0.66\text{SE}$, respectively.

Based on annual diver and snorkelers number estimated in 2018-2019, annual mean coral physical damage in all sites was significant with the annual mean diver number (ANOVA $p < 0.05$; $SS = 81.94$; $df = 1$; $F = 8.5$), and also with the mean snorkeler number (ANOVA $p < 0.05$; $SS = 90.57$; $df = 1$; $F = 8.9$). Mean damaged coral colonies differed significantly between HDI and LDI sites (ANOVA $p < 0.01$). The Pearson correlation coefficient of 0.99 indicates a positive relationship between the mean coral physical damage and the annual mean diver and snorkeler number.

At HDI sites T2 and T3, corals experienced a severe degree of physical damage, the prevalence of physical injury recorded 7.63%, and 8.86% during 2016, 15.91%, and 11.59% during 2017, 16.67%, and 13.46% during 2018, and 18.85%, and 20.73% during 2019, respectively. Whereas at LDI sites (T4) physical injury was documented comparatively lower. The prevalence of physical injury was recorded to be 1.42% in 2016, 1.69% in 2017, 2.35% in 2018, and 4.03% in 2019. Whereas at T1 prevalence of physical injury was documented to be 1.52% in 2016, 1.68% in 2017, 3.31% during 2018, and 2.7% during 2019 (Fig. 3).

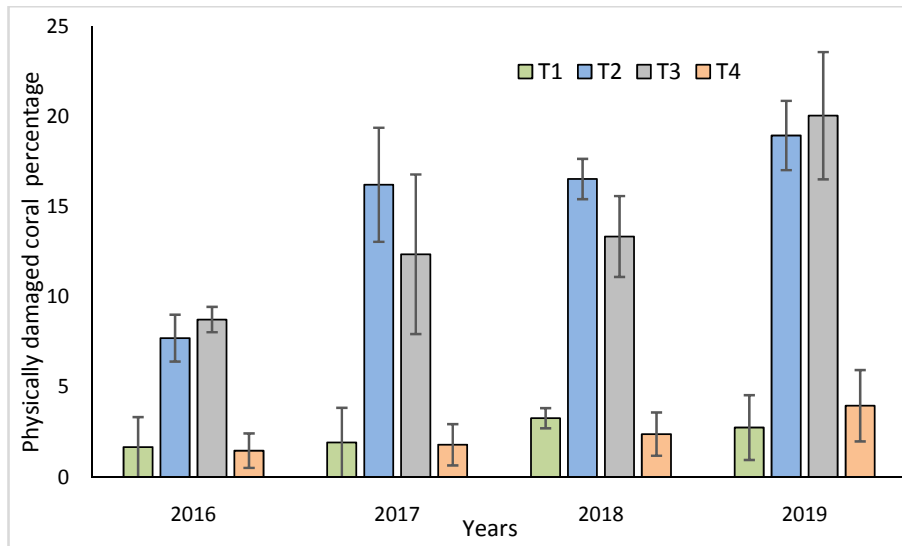


Fig. 3. Prevalence of coral physical injury (Mean±SE; broken and tissue damaged) during the study period.

Coral damage index (CDI) (Jameson et al. 1999) value exceeded the 4% ceiling value at both of the HDI sites throughout the four years of survey (at T2, CDI=7.63% in 2016; CDI=15.91% in 2017, CDI=16.67% in 2018 and at T3, CDI=8.76% in 2016; CDI=11.59% in 2017, CDI=13.46% in 2018); highest CDI value was observed in 2019 (CDI= 18.85% and 20.73% at T2 and T3 respectively). On the other hand, CDI value only crosses 4% cut off only during 2019 at the LDI T4 (CDI=4.03%), where the diving practice started in 2018.

Videos logs analysis

YouTube video analysis for the SCUBA divers' behavior showed that in 98.41% (n=124) of the video clips, the SCUBA divers had body contact and fin contact with corals. Other activities include touching, holding, sitting, standing, and walking on the coral colonies for maintaining underwater buoyancy and posing for photos/videos and eventually breaking corals. Nonetheless, another

detrimental practice observed was reef fish feeding (generally bread or rice) by tourists and diving operators to attract fish around the tourists. Fish aggregations were mostly comprised of the sergeant fish (*Abudefduf sordidus* and *A. bengalensis*), Demiselles (*Neopomacentrus violascens*, *N. cyanomos*), Damsels (*Cheiloprion labiatus*), and Moorish idol (*Zanclus cornutus*). Fish feeding practice was observed in 73.80% (n=93) of the videos. Further, in 19.04% (n=24) of the videos, divers were found to chase different species of reef fishes for photos/videos. Additionally, almost 97.62% (n=123) of the videos showed visibly damaged coral, which includes skeletal breakage, abrasion, tissue damage, growth anomaly, bleaching, macroalgal, algal turf and boring sponge growth on coral (supplementary Table 1). The most common behavior of divers was found to hold the *T. mesenterina* colony for balancing underwater buoyancy and capturing photos and videos. Video logs further showed that diving instructors encouraged tourists to hold the coral colonies to fix their position for photos and videos. Divers were also seen to walking, crawling, sitting, lying on coral colonies.

Quantification of boats, divers, and snorkelers

Recreational activities in the MPA restricted to fair-weather months from October to May (n=240 days). At the HDI site T2, mean number of dive boat visiting per day estimated as $20.5 \pm 1.32SE$, mean number of anchors were found to be $39.5 \pm 2.5SE$, mean divers were estimated to be $174.75 \pm 15.59SE$, mean number of snorkelers were calculated to be $181 \pm 12.02SE$. At HDI site T3, mean number of boats, anchors, divers, snorkelers were found to be $17.5 \pm 1.04SE$, $33.5 \pm 2.75SE$, $154.75 \pm 24.19SE$, and $172.25 \pm 13.60SE$, respectively (Fig. 4). At T1, no tourist activity was observed. Whereas at T4, a newly started diving site, mean of boats, anchors, divers, snorkelers recorded $5.00 \pm 0.57SE$, $10.00 \pm 1.15SE$, $31.25 \pm 4.87SE$, $33.75 \pm 5.35SE$, respectively. This study revealed that weekend holidays experienced a higher number of tourist arrival compared to working days. Divers per year (DPY) and snorkelers per year (SPY) at T2 were calculated to be 41940 individuals, and 43440 individuals, respectively. At T3, DPY was accounted to be 37140 individuals, and SPY was estimated to be 41340 individuals. Whereas at T4, DPY was estimated to be 7500 individuals, and SPY was 8100 individuals (Table 2).

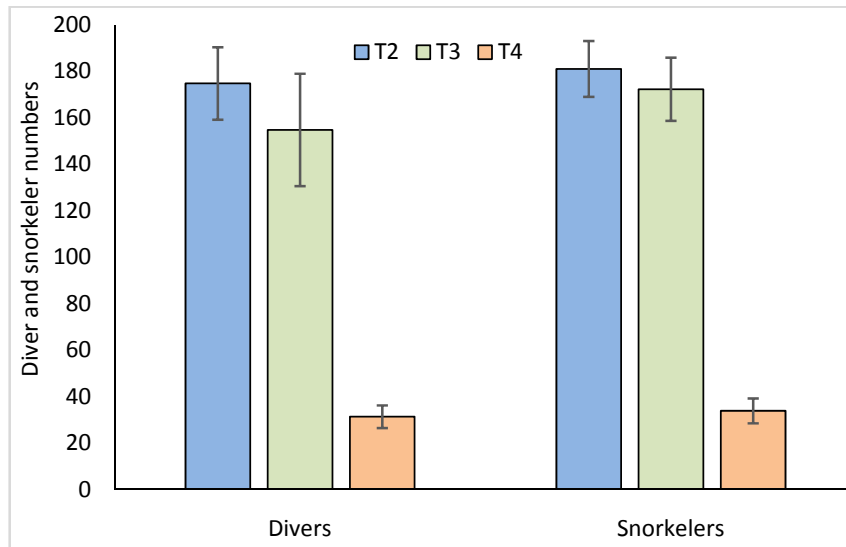


Fig. 4. Average number of divers and snorkelers per day at the HDI sites (T2 and T3) and LDI site (T4).

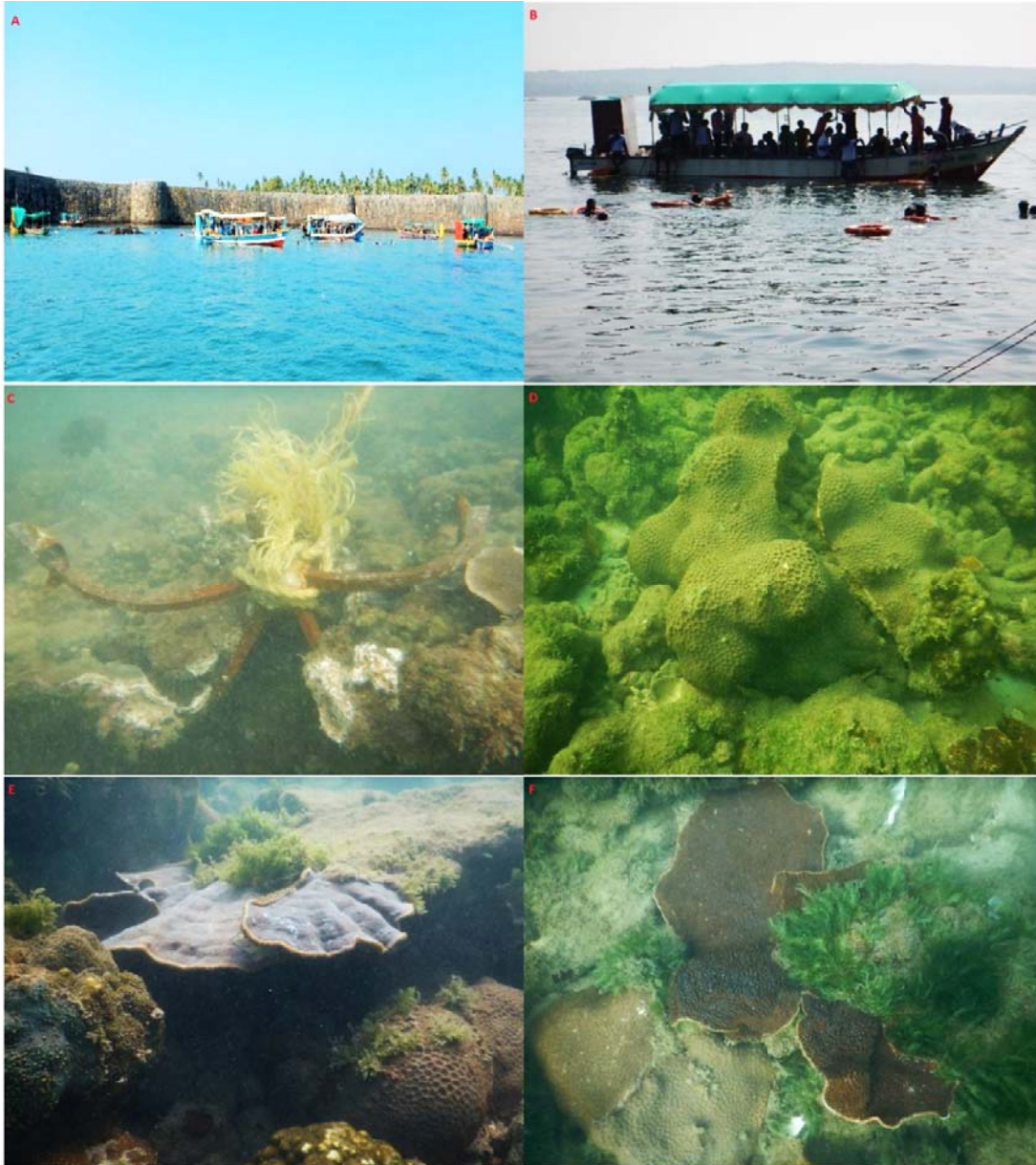


Fig. 5. Underwater photographic evidence of recreational diving and snorkeling impacts on coral in the MPA; A) assemblages of diving boats at shallow (2-4m) the diving site (11 boats in the frame); B) divers and snorkelers on a diving boat, total 35 people on the boat including crew member; C) boat anchor mediated coral damage; D) broken *Favites* sp. by boat anchor; E) up-rooted and overturned colony of *T. mesenterina*; F) settlement and growth of *Caulerpa* sp. on broken *T. mesenterina* colony.



Fig. 6A-F. Snapshots are taken from the videos analyzed for damaging activities, and diver's behavior at the MPA from <https://www.youtube.com> (links are provided in the supplementary file 1).

Table 2. Estimation of daily number (mean±SE) of boats, anchors, divers/estimated dives per year (DPY), snorkelers/estimated snorkelers per year (SPY) at study sites following Jameson et al. (1999).

Dive sites/Date	Boats	Anchors	Divers	Snorkelers/SPY
T2				
6-Oct-18	17	34	133	158
7-Oct-18	20	40	175	197
16-Apr-19	22	38	183	163
17-Apr-19	23	46	208	206
Mean±SE	20.5±1.32	39.5±2.5	174.75±15.59	181±12.02
DPY and SPY			41940	43440
T3				
6-Oct-18	18	36	131	146
7-Oct-18	15	30	107	153
16-Apr-19	17	28	162	187
17-Apr-19	20	40	219	203
Mean±SE	17.5±1.04	33.5±2.75	154.75±24.19	172.25±13.60
DPY and SPY			37140	41340
T4				
13-Oct-18	4	8	23	36
14-Oct-18	4	8	31	20
18-Apr-19	6	12	26	33
21-Apr-19	6	12	45	46
Mean±SE	5±0.57	10±1.15	31.25±4.87	33.75±5.35
DPY and SPY			7500	8100

Discussion

With the progress in developing nations, and the elevated financial status, the populace of many countries like India indulged in adventure tourism. Much of the elite goes abroad to exotic locations while middle to lower-middle-class ventures into tourist places within the country. In the recent past, Malvan(study area) has emerged as a budget tourist destination and has experienced sudden bloom(De et al., 2017, 2015; UNDP, 2011) for its coasts, cuisine, and pilgrimage in the nearby areas,while recreational diving being a recent addition.The price ofdiving tourism at the MPA varies at different diving shops and ranges from Rs. 500-1000 or approx. 8-14USD per person, which is far cheaper than the other diving destination in India like Goa, Lakshadweep, and Andaman and Nicobar Islands. The last decade experienced flourishing of this adventurous activity with the locals realizing

its potential as an alternative to hardship borne artisanal fishery (UNDP, 2011). However, our quantitative monitoring transects at three diving and control sites, qualitative analysis of video log broadcasting website (www.youtube.com), and direct quantification of plying boats and number of diving and snorkeling tourists' presents evidential testimony of detrimental activities resulting in coral damage. The present study exclusively analyses the socially evident parameters alongside supported by ground-truthing surveys of corals, disproving the counter-intuitive hypothesis 'ecotourism aids conservation.' The resulting analysis clearly implies that coral damage and associated mortality is the direct function of recreational diving also reported elsewhere (Giglio et al., 2020, 2016). Behavioral analysis suggests that tourists participate in these adventures for several reasons other than the affection for marine life, and the most probable reason is social media. Since the video log behavior showed that most of them carry less admiration for oceanic organisms and instead are eventful with camera-centric activities. Hence, the ignorance towards this diving footprint on marine life reveals a major conservation concern (reviewed in Giglio et al., 2020).

Video log analysis showed that diving operations carried out in the MPA neither follow the basic safety norms or standard SCUBA diving practices, nor the ethics of responsible diving. This analysis also raises questions on the legitimacy of the destructive diving practice in the MPA, wherein corals are protected as Schedule-I species under the Wildlife Protection Act (1972) of India. While the forest department and state biodiversity board, along with the tourism department, are striving hard for conservation of the MPA, but the habitat has been victimized by overwhelming tourism resulting in implementation letdown.

Physical damage to corals (Fig. 5) is well documented globally due to direct anchorage on corals, tourist standing, walking, holding coral for support, fin movement and jumping on shallow-water corals (Barker and Roberts, 2004; Chung et al., 2013; Hasler and Ott, 2008; Hawkins et al., 1999; Hawkins and Roberts, 1993; Juhasz et al., 2010; Krieger and Chadwick, 2013; Lamb et al., 2014; Roche et al., 2016). The present study categorically documents all activities mentioned above at the MPA, wherein the most damaging activity was identified as diver's physical contact with corals. The video log analysis has confirmed that the inexperienced tourists/divers hold coral colonies to counter underwater bouncy, which often leads to detachment and topples the entire coral colony. The prevalence of coral physical damage has increased from 4.83% in 2016 to 11.58% in 2019, which has resulted in cumulative physical damage of 33.08% in the last four years in the MPA.

Another noticeable detrimental behavior was reef fish feeding by dive operators in this MPA (Fig. 6F). Fish feeding practice by divers has reportedly increased worldwide, which could result in trophic alteration, malnutrition, and catalyze reef degradation (Brookhouse et al., 2013; Hémerly and

McClanahan, 2007; Paula et al., 2018). Moreover, coral reef recreational activity associated damages include direct impacts by boat hull, anchorage (Fig. 5) and propeller collision with corals and fishes, (Jones, 2007; Rogers and Garrison, 2001) wherein the damage of reef bottom could take more than a decade for recovery (Rogers and Garrison, 2001). Motorboat noise can also affect fish physiology, individual fitness, behavior, and population in the coral reef environment (Simpson et al., 2016; McCormick et al., 2018). Boat generated waves, chemical pollutants such as heavy metal, petroleum hydrocarbons, and antifouling paints further impact coral habitat negatively (Whitfield and Becker, 2014). Furthermore, boats and divers increase sediment resuspension, wastewater, nutrient discharge, and shoreline erosion (Hawkins et al., 1999; Lamb et al., 2014).

Estimation of carrying capacity for reef diving tourism is an important measure to evaluate how much diving pressure one reef can withstand without compromising reef health and species diversity over time; therefore, setting the diving limit is necessary for long-term sustenance of coral reef (Jameson et al., 1999; Wafar, 1997). Annual carrying capacity has been measured, and diving limits have been implemented in different reefs across the world (Table 3). However, in none of the Indian reefs, estimates of diving carrying capacity have been determined so far, and at the present MPA, carrying capacity exceeds many folds of the global average. The cumulative effects of several parameters indicate high Coral Damage Index (CDI) value due to remorseless diving activities and bleaching events during 2014-2016 due to sea surface temperature (SST) anomaly (De et al., 2015; Raj et al., 2018). Noting the recent world-wide coral reef decline triggered by recurrent mass bleaching events (Eakin et al., 2019; Hughes et al., 2018), recreational tourism mediated reef degradation will severely hinder the reef recovery processes (Giglio et al., 2020). Declining of reef ecosystem may have a wide range of possible effects on coastal human communities, including reduced food, income, and longer-term effects such as increased vulnerability to extreme weather events (Anthony, 2016; Pascal et al., 2016).

Table3. Carrying capacity estimated for sustainable recreational diving.

Estimated of scuba diver carrying capacity (individuals)	Reef location	References
4000-6000	Bonaire	Dixon et al., 1993, 1994
500	US Virgin Islands	Chadwick-Furman, 1996
Up to 5,000	Eastern Australia	Harriott et al., 1997
5000-6000	Egypt, Bonaire, and Saba	Hawkins & Roberts 1997, Hawkins et al. 1999
5000-6000	Eilat, Israel	Zakai& Chadwick-Furman, 2002
Up to 7000	Sodwana Bay, South Africa	Schleyer&Tomalin, 2000

Considering the present cumulative coral damage trend (Fig. 3), it can be predicted that the entire habitat will be altered and converted to a *non*-coral ecosystem in the coming years. The only possibility that the corals may survive beyond the mortality trend will be due to following reasons; 1) Unaffected reminiscent polyps with the ability to revive the colony; 2) Remaining unknown remote patches of corals that will sustain the local gene pool; 3) Larval flux from nearby habitats on the west coast; 4) Halting the deleterious ongoing activities with immediate effects.

The ignorance of tourists is not the primary cause of concern (considering the socio-economic status of the tourist-they are presumed oblivious), but the governance is in question, and more importantly, the accountability of local stakeholders for carrying out this activity unprofessionally. The stakeholders completely fail to realize the long-term loss behind this short-term monetary gain. The long-term loss will affect local stakeholders the most rather than the tourists or administration. This is a characteristic case of nonexcludable common resource mismanaged, considering it to be '*private goods*' resulting in a '*tragedy*' (Dietz et al., 2003). Marine resource mismanagement has resulted in collapse (McWhinnie, 2009), with a significant change in phenology (Enquist et al., 2014; Wabnitz et al., 2018), and in many cases bringing local extinction (Wabnitz et al., 2018). From commercial fisheries (McWhinnie, 2009), ecosystem services (Lant et al., 2008) to reef tourism (Hawkins and Roberts, 1993, 1992) all have resulted in widespread negative impacts primarily driven by a game skewed by selfish short-term gains (Hardin, 1968).

Hardin (1968) explained that common property could be used by society depending on the quality and quantity of property and funds received in that proportion sustainably. Nevertheless, in an

unmanaged situation (e.g., present study), it has open access for exploitation and attains a critical point of collapse, resulting in a '*tragedy of the commons*' wherein deterministic escalation ensues between the selfish users in which they are both the villains and the victims (Berkes, 1985). In the present case, the financial stability attained due to the recreational diving business will not keep the stakeholders underprivileged while allowing them to switch to new businesses or employments when the coral-based income ceases. Thus, it is not a classical '*tragedy of the commons*' (Hardin, 1968) for the corals (*commons*) as they carry dual protection, as scheduled under the Wildlife Protection Act (1972) and they reside in a Marine Protected Area wherein resources cannot be utilized. Considering the west coast of India, the rare and legally protected resource will be damaged considering it of '*commons*', bringing them to the brink of localized extinction. The stakeholders will not be affected by this '*tragedy*' as they will have alternative professions, after '*not so common*' resource vanishes.

In many cases, social media has been pivotal in the conservation of nature and wildlife (Wu et al., 2018), but ironically in the present case, it has been the culprit. Finally, a coral habitat in a MPA will be sacrificed for the financial upbringing of this coastal community; however, a sense of accountability can still keep the habitat alive. Damaging activities have to be halted in the immediate future by management intervention; otherwise, it will inevitably cease due to the non-existential status of corals. The currently unsustainable model of resource damage rather than optimum utilization requires reframing of conservation priorities with structured regulations aiming at sustainability (Bellwood et al., 2004; Mcleod et al., 2019).

Several cases have shown successful self-organized management of community-based public goods (Dietz et al., 2003; Ostrom et al., 1999) with equitable benefit sharing with a '*win-win*' cooperative game (Luttinger, 1997). Educating locals have shown promising results with a positive outcome of the reiterated public goods game (Kobori et al., 2016). Similarly, proper briefings and close supervision by the diving operator on tourists could reduce diver's impact on the reefs (Barker and Roberts, 2004; Giglio et al., 2020; Krieger and Chadwick, 2013). These results are alarming for the habitat and immediately demands carrying capacity studies for setting policies to improve tourism and enhance conservation; furthermore, it requires restoration measures (Horoszowski-Fridman et al., 2015; Nanajkar et al., 2019) to compensate the presently damaged coral community and to buffer them from other global stressors. India, as a developing country, is planning to declare new MPAs; however, pronouncement without legally binding implementations ultimately will not serve the purpose. This MPA declared 42 years back, might not remain a coral habitat if there are no

immediate actions taken to counter the local stressors in an era of rapid climate change, and we hope that the present study serves positively directional.

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References

1. Anthony, K.R.N., 2016. Coral reefs under climate change and ocean acidification: Challenges and opportunities for management and policy. *Annu. Rev. Environ. Resour.* 41, 59–81. <https://doi.org/10.1146/annurev-environ-110615-085610>
2. Barker, N.H.L., Roberts, C.M., 2004. Scuba diver behaviour and the management of diving impacts on coral reefs. *Biol. Conserv.* 120, 481–489. <https://doi.org/10.1016/j.biocon.2004.03.021>
3. Bellwood, D.R., Hughes, T.P., Folke, C., Nyström, M., 2004. Confronting the coral reef crisis. *Nature* 429, 827–833. <https://doi.org/10.1038/nature02691>
4. Berkes, F., 1985. Fishermen and ‘The tragedy of the commons.’ *Environ. Conserv.* 12, 199–206. <https://doi.org/10.1017/S0376892900015939>
5. Brander, L.M., Van Beukering, P., Cesar, H.S.J., 2007. The recreational value of coral reefs: A meta-analysis. *Ecol. Econ.* 63, 209–218.
6. Brookhouse, N., Bucher, D.J., Rose, K., Kerr, I., Gudge, S., 2013. Impacts, risks and management of fish feeding at Neds Beach, Lord Howe Island Marine Park, Australia: A case study of how a seemingly innocuous activity can become a serious problem. *J. Ecotourism* 12, 165–181. <https://doi.org/10.1080/14724049.2014.896369>
7. Carilli, J.E., Norris, R.D., Black, B., Walsh, S.M., Mcfield, M., 2010. Century-scale records of coral growth rates indicate that local stressors reduce coral thermal tolerance threshold. *Glob. Chang. Biol.* 16, 1247–1257. <https://doi.org/10.1111/j.1365-2486.2009.02043.x>
8. Chung, S.S., Au, A., Qiu, J.W., 2013. Understanding the underwater behaviour of scuba divers in Hong Kong. *Environ. Manage.* 51, 824–837. <https://doi.org/10.1007/s00267-013-0023-y>
9. de Groot, J., Bush, S.R., 2010. The potential for dive tourism led entrepreneurial marine protected areas in Curacao. *Mar. Policy* 34, 1051–1059. <https://doi.org/10.1016/j.marpol.2010.03.004>
10. De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., Mcvittie, A., Portela, R., Rodriguez, L.C., Ten Brink, P., Van Beukering, P., 2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosyst. Serv.* 1, 50–61. <https://doi.org/10.1016/j.ecoser.2012.07.005>
11. De, K., Sautya, S., Mote, S., Tsering, L., Patil, V., Nagesh, R., Ingole, B., 2015. Is climate change triggering coral bleaching in tropical reef? *Curr. Sci.* 109, 1379–1880.
12. De, K., Venkataraman, K., Ingole, B.S., 2017. Current status and scope of coral reef research in India: a bio-ecological perspective. *Indian J. Geo Mar. Sci.* 46, 647–662.

13. Dietz, T., Ostrom, E., Stern, P.C., 2003. The struggle to govern the commons. *Science* (80-.). <https://doi.org/10.1126/science.1091015>
14. Eakin, C.M., Sweatman, H.P.A., Brainard, R.E., 2019. The 2014–2017 global-scale coral bleaching event: insights and impacts. *Coral Reefs* 38, 539–545. <https://doi.org/10.1007/s00338-019-01844-2>
15. Enquist, C.A.F., Kellermann, J.L., Gerst, K.L., Miller-Rushing, A.J., 2014. Phenology research for natural resource management in the United States. *Int. J. Biometeorol.* 58, 579–589. <https://doi.org/10.1007/s00484-013-0772-6>
16. Flynn, R.L., Forrester, G.E., 2019. Boat anchoring contributes substantially to coral reef degradation in the British Virgin Islands. *PeerJ* 7: e7010. <https://doi.org/10.7717/peerj.7010>
17. George, R.M., Jasmin, S., 2015. Scleractinian coral diversity in Indian reefs, their threats and conservation, in: *Summer School on Recent Advances in Marine Biodiversity Conservation and Management*. CMFRI, Cochin, pp. 33–37.
18. Giglio, V.J., Luiz, O.J., Ferreira, C.E.L., 2020. Ecological impacts and management strategies for recreational diving: A review. *J. Environ. Manage.* <https://doi.org/10.1016/j.jenvman.2019.109949>
19. Giglio, V.J., Luiz, O.J., Schiavetti, A., 2016. Recreational diver behavior and contacts with benthic organisms in the Abrolhos National Marine Park, Brazil. *Environ. Manage.* 57, 637–648. <https://doi.org/10.1007/s00267-015-0628-4>
20. Guzner, B., Novplansky, A., Shalit, O., Chadwick, N.E., 2010. Indirect impacts of recreational scuba diving: patterns of growth and predation in branching stony corals. *Bull. Mar. Sci.* 86, 727–742.
21. Hardin, G., 1968. The tragedy of the commons. *Science* (80-.). <https://doi.org/10.1126/science.162.3859.1243>
22. Harrington, L.A., Macdonald, D.W., D’Cruze, N., 2019. Popularity of pet otters on YouTube: Evidence of an emerging trade threat. *Nat. Conserv.* 36, 17–45.
23. Hasler, H., Ott, J.A., 2008. Diving down the reefs? Intensive diving tourism threatens the reefs of the northern Red Sea. *Mar. Pollut. Bull.* 56, 1788–1794. <https://doi.org/10.1016/j.marpolbul.2008.06.002>
24. Hawkins, J.P., Roberts, C.M., 1993. Effects of recreational scuba diving on coral reefs: trampling on reef-flat communities. *J. Appl. Ecol.* 30, 25–30. <https://doi.org/10.2307/2404267>
25. Hawkins, J.P., Roberts, C.M., 1992. Effects of recreational SCUBA diving on fore-reef slope communities of coral reefs. *Biol. Conserv.* 62, 171–178. [https://doi.org/10.1016/0006-3207\(92\)91045-T](https://doi.org/10.1016/0006-3207(92)91045-T)
26. Hawkins, J.P., Roberts, C.M., Van’T Hof, T., De Meyer, K., Tratalos, J., Aldam, C., 1999. Effects of recreational scuba diving on Caribbean coral and fish communities. *Conserv. Biol.* 13, 888–897. <https://doi.org/10.1046/j.1523-1739.1999.97447.x>
27. Hémerly, G., McClanahan, T.R., 2007. Effect of recreational fish feeding on reef fish community composition and behaviour. *West. Indian Ocean J. Mar. Sci.* 4, 123–133. <https://doi.org/10.4314/wiojms.v4i2.28482>
28. Horoszowski-Fridman, Y.B., Brêthes, J.-C., Rahmani, N., Rinkevich, B., 2015. Marine silviculture: Incorporating ecosystem engineering properties into reef restoration acts. *Ecol. Eng.* 82, 201–213. <https://doi.org/10.1016/J.ECOLENG.2015.04.104>
29. Hughes, T.P., Anderson, K.D., Connolly, S.R., Heron, S.F., Kerry, J.T., Lough, J.M., Baird, A.H., Baum, J.K., Berumen, M.L., Bridge, T.C., Claar, D.C., Eakin, C.M., Gilmour, J.P., Graham, N.A.J., Harrison, H., Hobbs, J.-P.A., Hoey, A.S., Hoogenboom, M., Lowe, R.J., McCulloch, M.T., Pandolfi, J.M., Pratchett, M., Schoepf, V., Torda, G., Wilson, S.K., 2018. Spatial and temporal patterns of mass bleaching of corals in the Anthropocene. *Science* (80-.). 359, 80–83. <https://doi.org/10.1126/science.aan8048>

30. Jameson, S.C., Ammar, M.S.A., Saadalla, E., Mostafa, H.M., Riegl, B., 1999. A coral damage index and its application to diving sites in the Egyptian Red Sea. *Coral Reefs* 18, 333–339. <https://doi.org/10.1007/s003380050208>
31. Jones, R.J., 2007. Chemical contamination of a coral reef by the grounding of a cruise ship in Bermuda. *Mar. Pollut. Bull.* 54, 905–911. <https://doi.org/10.1016/j.marpolbul.2007.02.018>
32. Juhasz, A., Ho, E., Bender, E., Fong, P., 2010. Does use of tropical beaches by tourists and island residents result in damage to fringing coral reefs? A case study in Moorea French Polynesia. *Mar. Pollut. Bull.* 60, 2251–2256. <https://doi.org/10.1016/j.marpolbul.2010.08.011>
33. Kay, A.M., Liddle, M.J., 1989. Impact of human trampling in different zones of a coral reef flat. *Environ. Manage.* 13, 509–520. <https://doi.org/10.1007/BF01867685>
34. Kobori, H., Dickinson, J.L., Washitani, I., Sakurai, R., Amano, T., Komatsu, N., Kitamura, W., Takagawa, S., Koyama, K., Ogawara, T., Miller-Rushing, A.J., 2016. Citizen science: a new approach to advance ecology, education, and conservation. *Ecol. Res.* 31, 1–19. <https://doi.org/10.1007/s11284-015-1314-y>
35. Krieger, J.R., Chadwick, N.E., 2013. Recreational diving impacts and the use of pre-dive briefings as a management strategy on Florida coral reefs. *J. Coast. Conserv.* 17, 179–189. <https://doi.org/10.1007/s11852-012-0229-9>
36. Lamb, J.B., True, J.D., Piromvaragorn, S., Willis, B.L., 2014. Scuba diving damage and intensity of tourist activities increases coral disease prevalence. *Biol. Conserv.* 178, 88–96. <https://doi.org/10.1016/j.biocon.2014.06.027>
37. Lant, C.L., Ruhl, J.B., Kraft, S.E., 2008. The tragedy of ecosystem services. *Bioscience* 58, 969–974. <https://doi.org/10.1641/b581010>
38. Luttinger, N., 1997. Community-based coral reef conservation in the Bay Islands of Honduras. *Ocean Coast. Manag.* 36, 11–22. [https://doi.org/10.1016/S0964-5691\(97\)00014-8](https://doi.org/10.1016/S0964-5691(97)00014-8)
39. Majumdar, S.D., Hazra, S., Giri, S., Chanda, A., Gupta, K., Mukhopadhyay, A., Roy, S.D., 2018. Threats to coral reef diversity of Andaman Islands, India: A review. *Reg. Stud. Mar. Sci.* 24, 237–250. <https://doi.org/10.1016/j.rsma.2018.08.011>
40. Mcleod, E., Anthony, K.R.N., Mumby, P.J., Maynard, J., Beeden, R., Graham, N.A.J., Heron, S.F., Hoegh-Guldberg, O., Jupiter, S., MacGowan, P., Mangubhai, S., Marshall, N., Marshall, P.A., McClanahan, T.R., Mcleod, K., Nyström, M., Obura, D., Parker, B., Possingham, H.P., Salm, R. V., Tاملander, J., 2019. The future of resilience-based management in coral reef ecosystems. *J. Environ. Manage.* 233, 291–301. <https://doi.org/10.1016/J.JENVMAN.2018.11.034>
41. McWhinnie, S.F., 2009. The tragedy of the commons in international fisheries: An empirical examination. *J. Environ. Econ. Manage.* 57, 321–333. <https://doi.org/10.1016/j.jeem.2008.07.008>
42. Medio, D., Ormond, R.F.G., Pearson, M., 1997. Effect of briefings on rates of damage to corals by scuba divers. *Biol. Conserv.* 79, 91–95. [https://doi.org/10.1016/S0006-3207\(96\)00074-2](https://doi.org/10.1016/S0006-3207(96)00074-2)
43. Munjal, P., 2019. District-driven growth, a pilot study for making india a \$5 trillion economy: Report for Sindhudurg district. Delhi, India.
44. Nanajkar, M., De, K., Ingole, B., 2019. Coral reef restoration - A way forward to offset the coastal development impacts on Indian coral reefs. *Mar. Pollut. Bull.* 149. <https://doi.org/10.1016/j.marpolbul.2019.110504>
45. Ostrom, E., Burger, J., Field, C.B., Norgaard, R.B., Policansky, D., 1999. Revisiting the commons: Local lessons, global challenges. *Science* (80-.). 284, 278–282. <https://doi.org/10.1126/science.284.5412.278>
46. Pascal, N., Allenbach, M., Brathwaite, A., Burke, L., Le Port, G., Clua, E., 2016. Economic valuation of coral reef ecosystem service of coastal protection: A pragmatic approach. *Ecosyst. Serv.* 21, 72–80. <https://doi.org/10.1016/j.ecoser.2016.07.005>

47. Paula, Y.C. de, Schiavetti, A., Sampaio, C.L.S., Calderon, E., 2018. The effects of fish feeding by visitors on reef fish in a Marine Protected Area open to tourism. *Biota Neotrop.* 18, e20170339. <https://doi.org/10.1590/1676-0611-bn-2017-0339>
48. Picciulin, M., Sebastianutto, L., Codarin, A., Farina, A., Ferrero, E.A., 2010. In situ behavioural responses to boat noise exposure of *Gobius cruentatus* (Gmelin, 1789; fam. Gobiidae) and *Chromis chromis* (Linnaeus, 1758; fam. Pomacentridae) living in a Marine Protected Area. *J. Exp. Mar. Bio. Ecol.* 386, 125–132. <https://doi.org/10.1016/j.jembe.2010.02.012>
49. Raj, K.D., Mathews, G., Bharath, M.S., Sawant, R.D., Bhawe Vishal, Apte, D., Vasudevan, N., Edward, J.K.P., 2018. Climate change-induced coral bleaching in Malvan Marine Sanctuary, Maharashtra, India. *Curr. Sci.* 114, 384–387. <https://doi.org/10.18520/cs/v114/i02/384-387>
50. Rebolo-Ifrán, N., Graña Grilli, M., Lambertucci, S.A., 2019. Drones as a threat to wildlife: YouTube complements science in providing evidence about their effect. *Environ. Conserv.* 46, 205–210. <https://doi.org/10.1017/S0376892919000080>
51. Roche, R.C., Harvey, C. V., Harvey, J.J., Kavanagh, A.P., McDonald, M., Stein-Rostaing, V.R., Turner, J.R., 2016. Recreational diving impacts on coral reefs and the adoption of environmentally responsible practices within the SCUBA diving industry. *Environ. Manage.* 58, 107–116. <https://doi.org/10.1007/s00267-016-0696-0>
52. Rogers, C.S., Garrison, V.H., 2001. Ten years after the crime: Lasting effects of damage from a cruise ship anchor on a coral reef in St. John, U.S. Virgin Islands. *Bull. Mar. Sci.* 69, 793–803.
53. Sarkis, S., van Beukering, P.J.H., McKenzie, E., Brander, L., Hess, S., Bervoets, T., der Putten, L.L., Roelfsema, M., 2013. Total economic value of Bermuda's coral reefs: A summary, in: Sheppard, C.R.C. (Ed.), *Coral Reefs of the United Kingdom Overseas Territories*. Springer Nature Switzerland, pp. 201–211. https://doi.org/10.1007/978-94-007-5965-7_15
54. Simpson, S.D., Radford, A.N., Nedelec, S.L., Ferrari, M.C.O., Chivers, D.P., McCormick, M.I., Meekan, M.G., 2016. Anthropogenic noise increases fish mortality by predation. *Nat. Commun.* 7. <https://doi.org/10.1038/ncomms10544>
55. Spalding, M., Burke, L., Wood, S.A., Ashpole, J., Hutchison, J., zu Ermgassen, P., 2017. Mapping the global value and distribution of coral reef tourism. *Mar. Policy* 82, 104–113. <https://doi.org/10.1016/J.MARPOL.2017.05.014>
56. Terrón-Sigler, A., León-Muez, D., Peñalver-Duque, P., Torre, F.E., 2016. The effects of SCUBA diving on the endemic Mediterranean coral *Astroides calycularis*. *Ocean Coast. Manag.* 122, 1–8. <https://doi.org/10.1016/j.ocecoaman.2016.01.002>
57. Turner, J.R., Vousden, D., Klaus, R., Satyanarayana, C., Fenner, D., Venkataraman, K., Rajan, P.T., Rao, S.N.V., Alfred, J.R.B., Ramakrishna, Raghunathan, C., 2009. Coral reef ecosystems of the Andaman Islands: Remote sensing and rapid site assessment survey. *Rec. Zool. Surv. India* 301, 1–132.
58. UNDP, 2011. Mainstreaming coastal and marine biodiversity conservation into production sectors in the Sindhudurg coast, Maharashtra, India. Project document.
59. Venkataraman, K., Raghuraman, C., Raghuraman, R., Sreeraj, C.R., Immanuel, T., Yogesh Kumar, J.S., 2012. Scleractinia of Andaman and Nicobar Islands, Records of Zoological Survey of India. Zoological Survey of India, Kolkata, India.
60. Wabnitz, C.C.C., Lam, V.W.Y., Reygondeau, G., Teh, L.C.L., Al-Abdulrazzak, D., Khalfallah, M., Pauly, D., Deng Palomares, M.L., Zeller, D., Cheung, W.W.L., 2018. Climate change impacts on marine biodiversity, fisheries and society in the Arabian Gulf. *PLoS One* 13. <https://doi.org/10.1371/journal.pone.0194537>
61. Wafar, M.V.M., 1997. Carrying capacity of coral reefs, in: Regional Workshop on the

Conservation and Sustainable Management of Coral Reefs. pp. 65–70.

62. Whitfield, A.K., Becker, A., 2014. Impacts of recreational motorboats on fishes: A review. *Mar. Pollut. Bull.* 83, 24–31. <https://doi.org/10.1016/j.marpolbul.2014.03.055>
63. Woodland, D.J., Hooper, J.N.A., 1977. The effect of human trampling on coral reefs. *Biol. Conserv.* 11, 1–4. [https://doi.org/10.1016/0006-3207\(77\)90020-9](https://doi.org/10.1016/0006-3207(77)90020-9)
64. Wu, Y., Xie, L., Huang, S.L., Li, P., Yuan, Z., Liu, W., 2018. Using social media to strengthen public awareness of wildlife conservation. *Ocean Coast. Manag.* 153, 76–83. <https://doi.org/10.1016/j.ocecoaman.2017.12.010>