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REVIEW

The benefits and challenges of citizen science for coastal wetlands management in Andaman and Nicobar archipelago—a review

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Abstract

The coastal wetlands of Andaman and Nicobar Islands (ANI) constitute 98.6% of the total wetland area (143,238 ha) of the islands, out of which coral reefs and mangroves contribute most of the coastal wetlands (> 70%). Coastal wetlands of ANI deliver essential ecosystem services like shoreline stabilization, coastal protection, shelter for fishes, food, recreation, tourism, etc. The long-term sustainability of the coastal wetlands is also at stake due to the burgeoning human pressure, developmental activities, and natural hazards. Such impacts also cause the loss of wetland areas, the shift in biodiversity and interruption of their ecosystem services. The loss in wetland areas of ANI over the years also raises serious concerns about their management. Sustainable management of coastal wetlands requires continuous monitoring for effective management; however, the vast geographical area and remotely scattered Islands practically hinder the monitoring process, necessitating innovative approaches. This review presents the potential benefits of citizen science along with the challenges of managing coastal wetlands. The article also highlights the need for wide-range adoption of citizen science to sustain coastal wetlands.

Keywords Biodiversity · Reefs · Mangroves · Threats · Conservation · Policy · Citizen science

Introduction to the coastal wetlands

Wetlands are the most productive natural ecosystems that provide significant value in terms of biodiversity, ecosystem services, and economic goods (Biswas et al. 2010; Roy et al. 2017a, b). Wetlands also play a major role in regional sustainable development due to their ability to enhance resilience against extreme weather events (Chuang et al. 2018). Coastal wetlands include mangrove forests, coral reefs, salt marshes, beaches, estuaries, seagrass beds, and coastal water bodies lying within a depth of 6 m (Li et al. 2018; Ramsar Convention Secretariat 2016). Coastal wetlands offer important ecosystem services such as shoreline stabilization, erosion control, degradation of pollutants, groundwater recharge, and supply of freshwater (Bassi et al. 2014; Hushulong 2012; Patel et al. 2015; Renzi et al. 2019). Wetlands also play a major role in regional sustainable development due to their ability to enhance resilience against extreme weather events (Chuang et al. 2018). Coastal wetlands are also gaining worldwide attention as one of the most effective carbon sinks (Moraes 2018; Nag et al. 2019). Blue carbon systems such as mangroves, seagrass meadows, and salt marshes/tidal marshes are known to encompass a wide diversity of aquatic habitats that could absorb and sequester large volumes of carbon dioxide (ABC-News 2018; Bassi et al. 2014). However, due to rapid urbanization and land conversion projects for commercial purposes, the coastal wetlands are under threat (Barbier 2013; Blankespoor et al. 2014; Renzi et al. 2019). Loss of wetlands leads to a reduction in primary production by plants, that would have sequestered carbon in the future (Meng et al. 2019). India has a wealth of ecosystems, supporting diverse and unique habitats that provide several ecological goods and services; however, they are under tremendous pressure due to natural and anthropogenic activities (Bassi et al. 2014; Michener et al. 1997). Panigrahy et al. (2012) classified the coastal wetlands of India into natural wetlands (lagoons, creeks, sand/beach, intertidal mudflats, salt marsh, mangroves, seagrass beds, and coral reefs) and manmade wetlands (salt pans and aquaculture ponds). The complex and diverse assemblage of coastal wetlands (Michener et al. 1997) demands more innovative approaches to their conservation.

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The literature review was done through literature searches using websites like Web of Science (http://webofscience.com/), ScienceDirect https://www.sciencedirect.com/), GoogleScholar (https://scholar.google.com/), and ResearchGate (https://www.researchgate.net/) through standard keywords related to Citizen Science, Wetland Ecosystems and used a location reference in the keywords option to specifically skim articles from Andaman and Nicobar Islands (ANI). The articles that were not covered through the mentioned websites were traced through the Google Search engine to find additional related information.

Coastal wetlands of Andaman and Nicobar Islands (ANI)

The ANI, situated in the Bay of Bengal comprises 572 islands and is one of the biodiversity hotspots in India (Patankar 2019). The islands can be broadly classified into two groups: Andaman group in the Northern part and the Nicobar group in the Southern part. The two groups are separated by a ten-degree channel (Fig. 1). ANI being a tropical archipelago, marine fisheries along with the tourism sector focused on recreational activities, play an important role in providing livelihood to the inhabitants (Advani et al. 2013; Kiruba-Sankar et al. 2019, 2021a). Coral reefs and mangroves harbouring abundant fish diversity were found to be the most dominant coastal wetlands in ANI (Rajan et al. 2013). The tourism activities of ANI rely mainly on coral reefs and mangroves, which are among the best in India and harbour abundant coastal resources. Considering the prevalent dependency of the Island economy on these ecosystems, they must be conserved and protected to sustain the ecosystem services offered by them (Table 1).

Concerns arising in the coastal wetlands of ANI

The coastal wetlands of the Andaman and Nicobar archipelago are highly vulnerable to several extreme events. In ANI, a wetland area of 143,238 ha was identified during 2017–18, whereas during 2006–07 the wetland area was found to be 153,611 ha, which shows a reduction in wetland area by 10,373 ha (Gupta et al. 2021). Coral reefs and mangrove-based wetlands constituting almost 95% of the coastal wetlands form an important source of livelihood for the stakeholders in the ANI. However, these coastal wetlands are highly vulnerable to stress by various natural factors (Krishnan et al. 2011, 2012; Roy and Krishnan 2005; Sachithanandam et al. 2014; Yuvaraj et al. 2015). The dependency of the inhabitants on these ecosystems for fisheries, tourism, and recreation exposes them to anthropogenic disturbances. Table 2 summarizes some of the important issues faced by the coastal wetlands that need attention in terms of research and management. Issues such as plastic littering, invasive species and illegal exploitation of marine resources, also demand continuous monitoring and reporting so that appropriate actions can be taken. Sustainable management of these coastal wetlands is a key strategy to derive the long-term benefits offered by these wetlands. For sustainable management of coastal wetlands, innovative approaches are the need of the hour, and this review highlights how citizen science can be used to address this issue.

The concept and practice of citizen science

Citizen science, in general, engages citizens from non-scientific backgrounds in academic research projects (Tulloch et al. 2013). Citizen science is a powerful concept that enables community involvement in scientific observations (Dean et al. 2018; Garcia-Soto et al. 2021; Kasten et al. 2021) and sharing them with the scientist-in-charge of the study (Garcia-Soto et al. 2017). Citizen science programs undertaken in partnership between volunteers and scientists (Crall et al. 2011) have made a substantial contribution to science, education, and society (Haywood et al. 2016; Kobori et al. 2016). Citizen science approaches are also widely regarded for their effective contribution to policy, education, and science (Jones et al. 2018). Public members contribute to scientific research in various fields across the world (Martin et al. 2016) and are known to generate highly useful datasets and insights, which are otherwise unattainable by a small team of scientists (Thornhill et al. 2019). Citizen science aims to collect scientific data from the volunteers, however, it also directly or indirectly influences the volunteers to learn about the existing environmental issues, to understand the need to address such issues, to think critically about ecological and environmental sustainability, and to gain motivation for participation in scientific projects. Citizen science educates the volunteers through research organizations or implementing agencies on the key issues and projects, the success of which depends on their involvement and support. Citizen science activities also generate an increased understanding of scientific and ecological concepts (Vattakaven et al. 2022). Biodiversity-based citizen science projects are expanding rapidly, generating valuable datasets every year, and thereby building a case for public engagement in conservation projects (Burgess et al. 2017). Marine and coastal citizen science have evolved as a potential tool for marine biodiversity conservation and management (Cigliano et al. 2015; Sandahl and Tottrup

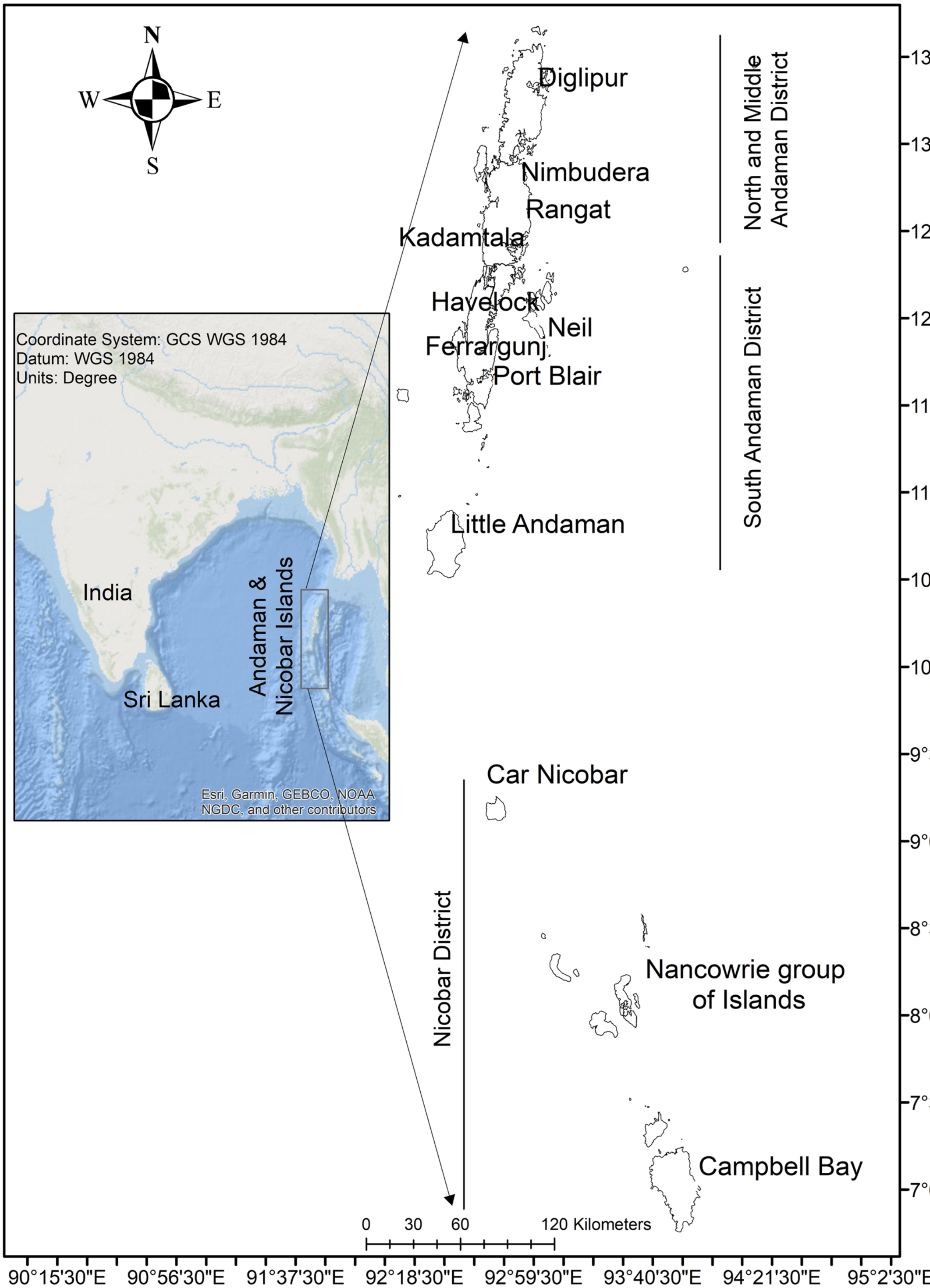

Fig. 1 Location of Andaman and Nicobar archipelago, India

2020; Turicchia et al. 2021) as volunteers participate in basic or applied aspects (McKinley et al. 2017), wholly or in parts (Chandler et al. 2017a, b).

Veeckman et al. (2017) outline different types of citizen science projects such as Crowdsourcing (where volunteers contribute their time and devices only), distributed intelligence (in which the volunteers provide interpretation or assist in the categorization of data or material), participatory science (here volunteers gather data under the control of researchers/organizers), extreme citizen science

Table 1 Some of the important coastal wetlands of the Andaman and Nicobar archipelago

Coastal wetlands	Andaman and Nicobar		References
	Area (ha)	Diversity (No. of species)	
Coral reef	54,770	577	Bahaguna et al. (2013), Mondal et al. (2016), Roy et al. (2017a), Gupta et al. (2021)
Mangroves	55,619	38	Chand et al. (2013), Ragavan et al. (2016), Roy et al. (2017a), Kathiresan (2018), Gupta et al. (2021)
Seagrass	1460	11	Immanuel et al. (2016), Geevarghese et al. (2017)
Lagoons	53	–	Gupta et al. (2021)
Sand/ Beaches	5275	–	
Salt marsh	6367	–	

Table 2 Some of the key issues confronting the coastal wetlands of Andaman and Nicobar Islands

S. no	Key /Major issues in coastal wetlands of Andaman and Nicobar that needs attention	References
1.	Mangrove Degradation	Chakraborty (2019), Veettil et al. (2020)
2.	Seagrass leaf reddening	Ragavan et al. (2013)
3.	Coral Mass bleaching	Krishnan et al. (2011), Lix et al. (2016), Malakar et al. (2021)
4.	Coral reef disease	Sreeraj et al. (2017)
5.	Invasive aquatic species through hull fouling	Raghunathan et al. (2021)
6.	Marine Plastic litter	Kaladharan et al. (2017), Saravanan et al. (2021). Kiruba-Sankar et al. (2023a)
7.	Natural disasters impact on marine ecosystems	Sachithanantham et al. (2014), Yuvaraj et al. (2015), Krishnan et al. (2012)
8.	Loss of wetland area over the decade	Gupta et al. (2021)

(wherein researchers and volunteers work together but volunteers takes up the major responsibilities), contributory project (projects run by researchers where volunteers are invited for data collection), collaborative project (volunteers can take part in different phases of a project such as analysis, interpretation, etc.), and co-created project (public develops the project in consultation with the researchers). Burgeoning environmental problems pose serious challenges in the conservation and management of bio-resources, wherein citizen science could probably assist in tackling these challenges (McKinley et al. 2017).

Citizen science initiatives in the Andaman and Nicobar archipelago

Few citizen science initiatives have already been taken up in the field of underwater observations related to coral reefs in the Andaman Islands. However, considering their potential and proven merits in the field of marine sciences, such initiatives should be popularised and adopted in more such projects. Some of the citizen science initiatives and the relevant activities wherein public knowledge has vastly supported the scientific programs are listed in Table 3. Often, such information from stakeholders comes through accidental observation and not through some systematic study. Scuba divers have played an important role in collecting information about reef-related activities. Fishermen and the public have also provided some useful information on the stranding of marine mammals, sighting data, etc. Citizen science programs, if operationalized effectively could support such information systematically and continuously, which could benefit the conservation and management of coastal wetlands. The only drawback with these studies is that the data could be collected only from a small geographical range or selected sites. Hence, there is an imminent need to popularize the concept of citizen science in the coastal wetlands in different parts of the ANI to gather a large amount of data. This data will facilitate in developing an extended understanding of the status of coastal wetlands and the issues being faced by them to devise appropriate management and conservation strategies.

Table 3 Citizen science projects implemented to study marine ecosystems in the Andaman and Nicobar Islands

S. no	Examples of information sharing through citizen science and other related studies in the Islands	References
1.	Dive communities were trained as citizen scientists to study benthic composition using biological indicators and photo quadrats. Data collection through an online database	The Rufford Foundation (2016) https://www.rufford.org/projects/nayantara-jain/harnessing-the-recreational-diver-community-in-india-for-coral-reef-monitoring-creating-a-citizen-science-protocol-for-the-andaman-islands/ https://reefwatchindia.org/initiative/#Andamans
2.	Reef log invertebrate slates popularized in the Andaman Islands using divers as citizen scientists to record rare underwater observations	Jagannathan (2021); Wagh et al. 2022 https://www.dakshin.org/underwater-citizen-science-designing-long-term-stakeholder-based-monitoring-schemes-for-indias-marine-system/
3.	The Department of Environment and forests recruited local volunteers and surveyed saltwater crocodiles to understand their habitat and behaviour	The Andaman and Nicobar Islands (2016) https://andamansblog.wordpress.com/2016/11/25/citizen-science-a-new-mode-of-action-based-environmental-education/
4.	Information on coral bleaching in 2010 and reef damage due to tropical storms in 2011 were assisted by SCUBA divers as they provided timely information on the instances of bleaching activity or reef damage	Krishnan et al. (2011, 2012)
5.	Pilot whale stranding reported was based on the tip of information obtained from local fishermen and the public	Raghunathan et al. (2013)
6.	SCUBA divers, researchers, residents, and fishermen provide useful information on the sighting of critically endangered giant guitarfish	Nazareth et al. (2022)

Review of relevant areas for citizen science in ANI

Coral reef monitoring

The importance of coastal wetlands such as coral reefs for ANI was highlighted in the previous sections. Due to climate change coral reefs are constantly exposed to threats like an increase in sea surface temperatures (SST) (Krishnan et al. 2011; Majumdar et al. 2018; Parkinson et al. 2016) and other extreme events (Krishnan et al. 2012; Roy et al. 2014) like associated bleaching events, that are some of the imminent threats faced by coral reef ecosystems in the Islands (Krishnan et al. 2011; Marimuthu et al. 2012). About 73% of the marine fishes (1089 species) reported from the ANI are known to inhabit the reef ecosystem (Rajan et al. 2013). The economy of ANI is predominantly tourism-based with a special focus on coastal tourism activities such as scuba diving, snorkeling, sea walks, and beach recreational activities. The impact on coral reefs could also practically affect the tourism sector of the Islands. Conservation and sustainable management of reef ecosystems can be achieved through the implementation of citizen science projects. Citizen science projects can provide practical solutions to the issues faced. Studies on coral reef health reported by Krishnan et al. (2011) practically used the data provided by scuba divers in reporting coral reef health. As reef health monitoring is an underwater activity, scuba divers and snorkelers could be suitable citizen scientists to monitor the health of coral reefs and data collection on reef health, as they engage in diving activities on a day-to-day basis at different recreational locations. Some of the programs across the world where reef monitoring activities were taken up through citizen science are listed in Table 4. Citizen scientists should also be identified for other vulnerable areas such as marine national parks, closed areas, and other areas where coral reef diversity is higher but not frequently assessed so that the data collection process covers a wide spatial area because scuba divers don't have access to a lot of locations since they only have recreational dives with tourists at specific places of interest and do not cover a wide range of sites. A marine citizen science initiative named Reef Log was launched as a pilot study in the Andaman Islands by a team of researchers from Dakshin Foundation, India engaged scuba divers as volunteers for gathering scientific information (Jagannathan 2021). Such initiatives should be expanded further across the archipelago to study and understand the health of coral reefs under the impending climatic conditions. Considering the incidences of reef bleaching in the recent past, citizen science surveys using colour charts as mentioned in Table 4 could generate useful information to monitor the beaching and health of coral reefs.

Monitoring the mangroves

Blue carbon sinks, such as mangroves, and seagrass meadows, are known to be important in sequestering carbon dioxide and mitigating climate change impacts (Mcleod et al. 2011; Ragavan et al. 2019). A key challenge for blue carbon management is integrating the social and cultural dimensions within governance mechanisms. Mangroves have been closely associated with the coastal population who depend on them for various ecosystem services (Friess et al. 2021; Rasquinha and Mishra 2021) such as fuel, fodder, medicine, recreation, tourism, education, fishery habitats, fish breeding grounds, coastal protection, shoreline management, accretion, etc. (Chand et al. 2013). Mangrove ecosystems, characterized by unique species of trees and shrubs, support wetland communities (Macintosh and Ashton 2002) and also protect the coasts against natural disasters and extreme events (Roy and Krishnan 2005; Kiruba-Sankar et al. 2018a). Mangrove ecosystems were found to be rapidly declining worldwide due to various natural and anthropogenic threats (Friess et al. 2021; Silkamaki et al. 2012). India has the highest record of mangrove biodiversity in the world, with several associated floral (algae, bacteria, actinomycetes, lichens, associated plants) and faunal (prawns, crabs, insects, molluscs, fishes, amphibians, reptiles, birds, mammals) groups (Kathiresan 2018). ANI are home to 38 true mangrove species and several mangrove associates (Ragavan et al. 2016). The Indian Ocean earthquake and tsunami of 2004 have severely affected the mangrove stands of the Andaman Islands (Roy and Krishnan 2005; Ramakrishnan et al. 2020). Mangroves are generally undervalued in Southeast Asia in decision-making on use, conservation, and restoration (Romanach et al. 2018). Innovation approaches are the need of the hour to conserve and protect the mangrove ecosystem. Citizen scientists can be engaged in mangrove monitoring programs such as bird watching in mangroves, sighting predators, reporting mangrove flowering and fruiting (studying their reproductive cycle), and surveillance of anthropogenic activities such as littering, vandalism, and poaching in mangrove areas. Mackenzie et al. (2013), in their mangrove watch program, report the effectiveness of engaging the local staff and community members in providing data on the extent, structure, and condition of shoreline habitats. The major steps followed in their mangrove watch programs were community training and information sessions for volunteers, participants recording geotagged videos of shorelines, video data being transferred to the scientific experts, and experts assessing the data provided and sharing the feedback with coastal stakeholders (Mackenzie et al. 2013). Some of the

Table 4 Successful reef ecosystem-based citizen science programmes and the suitability of their implementation in ANI

S. no	Reef based citizen science projects	Process Brief	Implications	Suitability in Andaman Islands	References
1	Coralwatch programme	Citizen scientists use color scores of the corals and compare them with a coral health chart	Identification of healthy and bleached coral reefs based on the colour of the observed reefs	The threat of coral bleaching is severe in Andaman due to elevated sea surface temperature patterns. Monitoring reefs using colour charts could be a simple and reliable indicator of reef health. Such methods can be widely adopted wherein scuba divers, snorkelers, and tourists can also contribute if sensitized and trained properly	Marshall et al. (2012); Coralwatch 2023 (https://coralwatch.org/index.php/monitoring/survey-methods/)
2	Training programs for citizen scientists	In this reef monitoring program, the volunteers were subjected to scuba training followed by reef ecology courses with theory and field sessions. Volunteer knowledge was also compared with researchers before data collection	These programs taught the volunteers basic community-based coral reef health monitoring protocols so that they could effectively collect reef data and contribute to scientific knowledge	In such reef monitoring programmes, scuba divers are to be engaged with some additional level of training and exposure. Underwater citizen science such as Reeflog launched in Andaman also used scuba divers as volunteers	Gouraguine et al. (2019)
3	Reef Check Australia	Citizen scientists first engage in surveyor training, practice, and demonstration of trained skills, taking up the standardized survey methods with protocol, site selection, and data collection			Reefcheckaustralia 2021 (https://www.reefcheckaustralia.org/about) (https://www.reefcheckaustralia.org/methods)
4	Reef life survey	Underwater visual census program using transects and quadrats where the diver records fish and invertebrate species in the reef ecosystems. An excel template is provided to enter the data and submit the same for further analysis	This program helps in collecting species data from citizen scientists (divers) on rare sightings and phenomena encountered during their dives		Edgar et al. 2020

Table 5 Successful mangrove ecosystem-based citizen science programmes and the suitability of their implementation in ANI

Citizen science programmes	Process brief	Implications	Relevance to the Andaman and Nicobar Islands	References
Incidences of diseases in mangroves	Volunteers will collect and analyze the mangrove leaves through sampling	The observations could be useful to understand the impact of natural or environmental stressors on the mangrove environment	This could add a new dimension to mangrove research in the Islands as such studies are limited. The information could be highly relevant	Mangrove detectives (2019) https://mangrovedetectives.org/lessons/outbreak-investigation/
Leaf grazing of mangroves by insects	Volunteers may collect and study the area of leaf grazed	Good information on the loss of leaf coverage due to pests	These studies could provide new insights into mangrove research	Mangrove detectives (2019) https://mangrovedetectives.org/lessons/secret-agents/
Mangrove restoration projects	Volunteers may plant mangrove samplings in areas where mangroves were affected due to natural and anthropogenic disturbances	Mangrove afforestation could strengthen coastal conservation and could act as Bioshield. Such initiatives would also strengthen the blue carbon programs	ANI being comprised of small Islands remains highly vulnerable to natural stressors. Mangrove afforestation protects the coasts as bioshield	University of the Virgin Islands (2022) https://www.uvi.edu/community/virgin-islands-marine-advisory-service/citizen_science.aspx
Shoreline video assessment method of mangroves	Volunteers collect images of shoreline habitats that would be analyzed to understand the condition	Could be useful in understanding the shoreline changes and their monitoring over a period of time	Could provide much useful information on the shoreline habitats. However, access to the sites could be a gap to address	Reefcitizensciencealliance (2022) https://www.reefcitizenscience.org/organisations/mangrovewatch
Mangrove health index data	Volunteers collect, process, and analyze mangrove data to develop health index for mangroves using mobile apps	Volunteers particularly the coastal communities residing closer to mangroves can particularly provide good real time data if trained properly	The entire stretch of the archipelago has mangroves and dependent communities. They can be motivated to data collection	The World Bank (2021) https://www.worldbank.org/en/news/feature/2021/07/26/mangrove-conservation-and-restoration-protecting-indonesia-climate-guardians

other citizen science programs related to mangroves are listed, and their applicability in ANI is summarized in Table 5. However, as highlighted in various case studies, training and capacity building for the identified volunteers form a crucial component in citizen science to gather reliable data.

Monitoring seagrass meadows

Seagrass meadows are complex socio-ecological systems (Jones et al. 2018) in shallow marine tropical regions (Sachithanandam et al. 2014), which also offer multiple ecosystem services (Mazarassa et al. 2018), and are one of the most productive habitats in the world (Lyimo et al. 2018; Ramesh et al. 2018). Some of the important ecosystem services of seagrasses include coastal protection, shore nourishment (Paul 2018), long-term carbon storage (Lyimo et al. 2018), supporting rich fish diversity that engages small-scale fishers (Ramesh et al. 2018; Wallner-Hahn and Torre-Castro 2018). Seagrasses are also well known for providing habitat for vulnerable marine mammals such as sea cows and sea turtles (Ramesh et al. 2018; Cullen-Unsworth et al. 2018). Despite the conservation efforts of seagrass meadows in selected areas, most of them remain under significant pressure leading to decline and loss of function (Unsworth et al. 2019). Around 15 species of seagrasses are reported from India, of which 11 are represented in the ANI (Savurirajan et al. 2015; Immanuel et al. 2016). Out of the 1434 fish species reported from ANI, 152 fish species are reported from seagrass meadows in the islands (Rajan et al. 2013). Like mangroves, seagrasses are also gaining wider attention due to their blue carbon potential. However, unlike mangroves, the seagrasses are more vulnerable to extreme events such as the Lehar cyclone in 2013 (Sachithanandam et al. 2014), tidal fluctuations and need to be properly conserved to sustain the ecosystem services provided by them. Seagrasses inhabiting shallow intertidal to subtidal areas are easily accessible either by foot or snorkeling (Unsworth et al. 2019), which makes their monitoring comparatively easier. However, between intertidal and subtidal seagrass meadows, the intertidal meadows are also exposed to more extreme and variable environmental conditions (Mazarassa et al. 2018). Hence there is a greater potential for the application of citizen science initiatives towards conservation and monitoring of intertidal seagrasses, which are vulnerable to extreme conditions. Jones et al. (2018) outline the potential seagrass citizen science program with a biological, ecological, and socio-economical focus, which includes the identification of flower occurrence, diseases, the site-specific abundance of seagrasses and fishes, marine mammals in seagrass meadows, and historical changes in their extent, threats, and

Table 6 Successful seagrass ecosystem-based citizen science programmes and the suitability of their implementation in ANI

Seagrass based citizen science projects	Process brief	Implications	Relevance to the Andaman and Nicobar Islands	References
Seagrass spotter	Citizen scientists provide comprehensive pictures of seagrass meadows across the world	Site-specific conservation and species-specific action plan	The Islands have seagrass meadows which were vulnerable to natural disasters. Volunteers can greatly assist in the location of seagrass meadows for their protection	Seagrass-spotter (2021) https://seagrassspotter.org/
Seagrass watch	Volunteers identify the areas important for seagrass diversity through field surveys	Conservation and management become easier with access to multiple locations	The study can provide critical seagrass meadow locations from a conservation point of view	Seagrass-watch (2022) https://www.seagrasswatch.org/seagrasswatch/
Community seagrass initiative (CSI)	Trained volunteers gather information on seagrass beds and monitor their health using SCUBA	Seagrasses are known to be more vulnerable as many species remain exposed during low tides	Seagrasses can be easily accessible in low tides and mapping and monitoring of such vulnerable locations through a community-based approach could greatly help in achieving conservation goals	Jones et al. (2018) Zooniverse (2022)

fishery. Some of the most familiar seagrass citizen science programs are listed in Table 6.

Addressing the issue of marine debris

Studies on beach littering in Indian coasts revealed that the beaches of Andaman Islands fell under the category of extremely littered beaches with > 100 g/m^2 along with other popular coastal tourism states such as Karnataka, Goa, and Gujarat (Kaladharan et al. 2017). The issue of marine debris is even noted from the far-flung Nicobar group of Islands, which comprise mostly floating debris washed from passing ships or from adjacent countries aided by sea surface currents and anthropogenic activities (Dharani et al. 2003; Kiruba-Sankar et al. 2023a). Along with recreational beaches, fish landing centers and associated coastal waters were also becoming a spot for the accumulation of debris and pollution (Seetharaman et al. 2015; Saravanan et al. 2021). Hidalgo-Ruz and Theil (2015) report that citizen science can be a useful approach to assessing marine litter sources, distribution, and ecological impacts. Scuba divers acted as citizen scientists, and the details of the debris collected were also recorded through mobile apps developed for debris management, viz., Dive Against Debris (Mongabay 2017) and Clean Swell mobile application program for debris. Dive against debris is an organized scuba specialty course accessed through Professional Association of Diving Instructors (PADI) dive courses wherein scuba divers were trained to engage in ocean cleanup activities to remove trash from their local dive sites (PADI 2022). The Clean Swell mobile application allows the volunteers with a download and sign in process to record the trash collected, the distance covered, and the total weight of trash collected, and the data collected can be submitted into the database for providing solutions (Ocean Conservancy 2022). Mobile applications can be the best medium for the collection of data on marine debris, as volunteers can upload photographs of debris-prone areas so that appropriate action can be initiated to clear the debris. Velde et al. (2017), in their citizen science programs, engaged school students and teachers as volunteers to collect data on marine debris. Their study revealed processes such as identification of the study area, understanding and identifying the debris, and identifying the category of debris, followed by data collection and data inputs into an online database (Velde et al. 2017).

Marine mammal sightings

Coastal wetlands are also habitats for marine mammals, birds, and saltwater crocodiles. Shallow coastal wetlands could also be accidental stranding sites of whales and dugongs, which makes these habitats critical from the point of conservation. The incidences of whale stranding in the ANI is a classic example wherein prompt public information could be beneficial (Raghunathan et al. 2013; Mohan and Sojitra 2018). Despite the conventional management procedures and actions, citizen science approaches could assist in covering a wider spatial range and provide more comprehensive information on any incidence of stranding of these vulnerable faunal groups. Volunteers engaged in other citizen science projects, local communities residing near coastal wetlands, students, and the public may be sensitized to report such incidents through a helpline number or a mobile application so that appropriate action can be initiated promptly. Historical geo-referenced sighting data can be collated with the assistance of citizen scientists, and a comprehensive map of sightings can be developed for conservation and management purposes. The potential role of local ecological knowledge in the sighting of Giant guitar fishes has provided useful insights into the ANI (Nazareth et al. 2022). In Kenya, Kenya Marine Mammal Network (KMMN) is a well-established citizen science program that contributes to understanding the prevalence and distribution of small cetaceans through surveys, opportunistic sightings, and participatory citizen science (Mwangombe et al. 2021). Understanding the local ecological knowledge along with participatory citizen science could provide useful insights into the marine mammal sighting projects in the Andaman Islands.

Tracking the invasive species

Biological invasions are one of the most challenging ecological and environmental issues faced globally (Encarnacao et al. 2021). The issue of effectively addressing invasive species is seen as a significant problem by wetland restoration professionals (Stelk and Christie 2016). Intentional introductions of non-native species into any new ecosystem are intended to enhance local fisheries and aquaculture systems or biological control of weeds, pests, and vectors of diseases (Daryadel and Talaei 2014). Such introductions risk their accidental entry into coastal wetland habitats, which could be detrimental as they would affect the natural ecosystem by altering or modifying the ecological setup and causing ecological imbalances (Chakraborty 2019). Responses against invasive species necessitate novel strategies that account for ecological and societal complexities (Scyphers et al. 2015). The possible effect of invasive species on the native aquatic fauna is particularly of concern as tropical islands harbor various endemic species, which are of great significance to the ecosystems. Citizen science is widely regarded as a tool in alien species management and the conservation of biodiversity (Clements et al. 2021; Kousteni et al. 2022). Scyphers et al. (2015) report that non-traditional data sources are effective at detecting and tracking rapid marine invasion, as documented in the case of Lionfish. Delaney et al. (2007) used citizen scientists' data to establish a large-scale database on the abundance and distribution of native and invasive crabs. In ANI, marine species invasions are rarely reported, while the increasing demand for freshwater fish in the Islands has paved the way for non-native fish introductions in the Islands (Kiruba-Sankar et al. 2018b, 2021b, 2022; Rajan and Sreeraj 2014; Surendran and Vasudevan 2013). The issue of marine invasive species in the ANI has been discussed in the studies of Raghunathan et al. (2021). The reef log initiatives can be the best method to monitor the invasive species as SCUBA divers can record such unusual observations during their dives, and the information can be collected at scientific levels for further appropriate action. Kousteni et al. (2022) used citizen scientists such as school children, students, divers, naturalists, and various volunteers to study alien species detection in European marine waters. Studies in the United States revealed the citizen science program on assessing the presence of native and invasive crabs in the Intertidal areas wherein students played a major role as volunteers (Delaney et al. 2008).

Turtle conservation programs

Andaman and Nicobar are some of the very important turtle nesting grounds of the Giant Leatherback turtle, Hawksbill turtle, Olive Ridley turtle, and Green turtles (Namboothri et al. 2010; Swaminathan 2018; Mongabay 2021). The sea turtles distributed across the archipelago are well known for their seasonal nesting habitats, particularly the Giant Leatherback (*Dermochelys coriacea*). Studies on the migratory pattern of Giant leatherback turtles were also reported by Swaminathan et al. (2019) in the ANI. Places such as Little Andaman, North and Middle Andaman, Little Nicobar, and Great Nicobar are some of the important turtle nesting sites in the archipelago (Times of India 2016; Swaminathan 2018; Firstpost 2019; Mongabay 2021). Sea turtles remain highly vulnerable to natural and anthropogenic stressors. Some of the important issues outlined in sea turtle conservation were associated with fishing activities, coastal development process, direct take of turtles by humans, pathogens, pollution, and global warming. In the case of ANI, the need for long-term monitoring of the nesting sites, accessibility of the sites, protection from predators, and intensive surveys in important nesting sites are recommended in the studies of Swaminathan et al. (2017). Conservation projects essentially need the cooperation of the stakeholders or volunteers who can help in real-time monitoring or who can provide valuable data sets. Citizen science activities can greatly assist in the monitoring and data collection programs. Identification of the turtle tracks could be a good initiative for entry-level volunteers. Such track mark identification and associated nest counts were also reported in the study by Ceriani et al. (2019). Studies by Swaminathan et al. (2017) also used turtle tracks as a tool to identify the important nesting features in the Nicobar Archipelago. Turtle track marks can also be reliable in the remote locations of the Andaman and Nicobar archipelago, where there is limited access to the public as the track marks can remain intact for some time to undertake observations, especially in the case of the Giant leatherback turtle. Scuba divers and tourists use mobile applications such as TurT (Turtle uniting researchers and Tourists) to record and upload photos of turtles they encountered during their dives (ESRI 2020). In India, a citizen science initiative named KURMA—Tracking Indian Turtles and Tortoises, aims to understand turtle biodiversity and associated features through citizen science initiatives (Dutta et al. 2020). Likewise, volunteers can be trained on the identification of sea turtles, turtle tracks and nesting features, so that they can collect data based on the platform in which they are trained, preferably through mobile applications or a web-based submission process. Online platforms using mobile applications can be useful so that volunteers can take photos of nesting sites, turtle tracks, species identification, and turtle spotting on beaches, which can be tagged along with the georeferenced points or locations with date and time so that it can be collated at a common point for analysis and interpretation (Dutta et al. 2020). Citizen science can particularly be very helpful in remotely located islands like the Nicobar group, where public access is very limited. Local traditional communities can be trained as citizen scientists so that data can be collected over a period and the knowledge base of turtle nesting can be updated through citizen science. Local ecological knowledge of the stakeholders can also help understand the turtle tracks and nesting sites (Kiruba-Sankar et al. 2023b, 2023c). Long-term monitoring and capacity-building/training were the key recommendations in the study of Namboothri et al. (2010) to conserve and protect the leatherback turtles on the Islands. Coastal wetland ecosystems are also known to be an important habitat for birds in ANI. Post-tsunami and earthquake of 2004, new wetlands have formed due to seawater inundation, which have become habitats for birds (Roundglassustain 2022). Citizen science projects on water bird census were taken in ANI for the management of wetlands and water birds (Wetlands International 2020). Citizen science initiatives through the Andaman Avian Club have generated large-scale data on wetland birds and their habitats (Andamansheekha 2023). With such vast applications in various areas, citizen science has immense potential to garner larger datasets for future wetlands conservation projects.

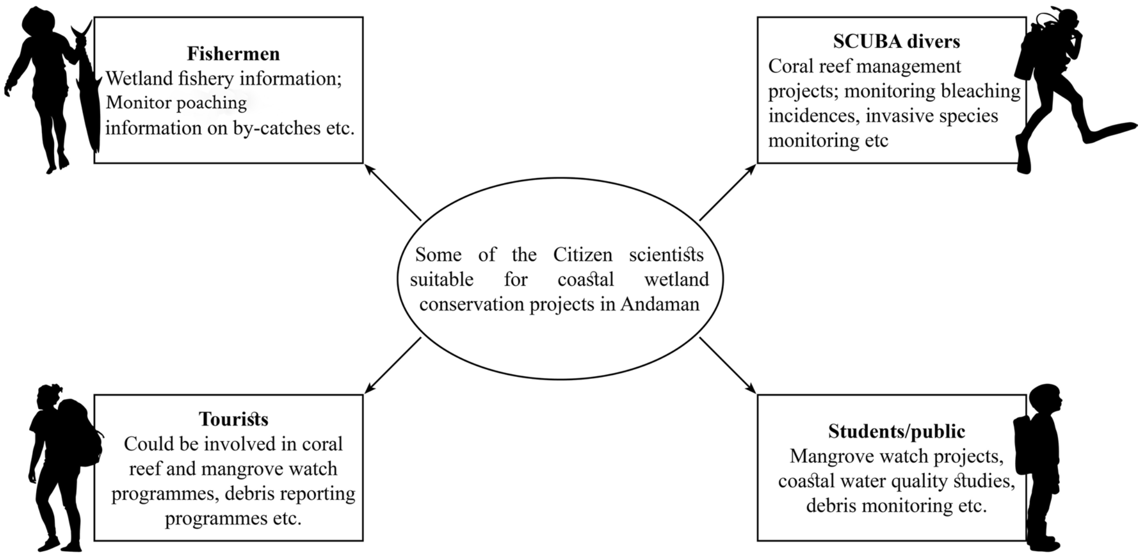

Fig. 2 Some of the potential citizen scientists who can be engaged in projects

Key considerations in citizen science projects

Although citizen science programs have tremendous applications in conservation and management practices, some of the key areas that need due attention are outlined herewith.

Volunteer identification

Volunteer engagement is a key component for successful outcomes in citizen science (Vattakaven et al. 2022). An important component in the citizen science approach is identifying the right volunteer for the job envisaged. This could also be a major hurdle for the successful implementation of the project. In tropical islands like ANI, a high number of stakeholders depend on marine resources for livelihood, employment, and science. Some of the important stakeholders are scuba divers, fisherfolk, coastal tourism operators, students (school and college), marine exporters, and NGOs which can be involved in the collection of scientific data (Fig. 2). However, every group will have its priorities and engagements. Martin et al. (2016), in their online surveys, assessed the interests of volunteers in citizen science programs. Such studies should be undertaken to assess the level of interest and their time-sharing capabilities. Except for students, many other stakeholders are involved and spend considerable time in their prioritized activities. The time that they could spend on the citizen science projects could be a limiting factor. However, the importance of their contribution cannot be ruled out, as even routine observations and recordings could also provide valuable information. Adopting a flexible approach is also essential as different participants have different exposure.

Understanding the knowledge level of volunteers

Involving public citizens in research programs needs a proper one-to-one dialogue to understand their roles and responsibilities. Apart from the identification of volunteers and assessing their interests, understanding the knowledge gaps is crucial so that they can be trained properly before assigning specific tasks. Again, manpower training or brainstorming programs are essential to sensitize the groups willing to participate. Their grasping tendency is more crucial towards understanding the task that they are going to perform and the benefits that could be reaped through their services. The citizens might show greater interest in the initial phases of the project; however, their involvement might decline at later stages due to other engagements. Discontinuities in their involvement might also affect the project's progress. Environmental education programs through citizen science are the best way to generate awareness of environment-related issues in the short term (Meschini et al. 2021). Such awareness generation could help identify the right volunteers for different projects. Awareness generation and education programs could also be helpful in the up gradation of knowledge of the citizen scientists who will provide their expertise in the collection and reporting of data. Such education programs can also help avoid sampling errors and the gathering of quality data. Education learning outcomes should also be aligned with citizen science goals for better execution of the projects (Roche et al. 2020).

Quality of data collection

Citizen science projects are often criticized for the inaccuracy of collected data and sampling biases (Gacutan et al. 2022). Such an issue also needs proper attention and care (Irwin 2018) so that the data collected can largely be reliable. Addressing the authenticity issues in data collection could be challenging, especially when volunteers are new to the exposed field (Bonney et al. 2009). For instance, a scuba diver, if engaged as a volunteer in underwater citizen science projects, often has vast expertise on the study area and the site and hence could provide handy information, and the training component for such volunteers is relatively easy. Cautious uptake of citizen science data by the scientific community is often related to concerns about data quality (Brewin et al. 2017). Poorly documented data or flaws in the data collection process could also mislead the situation (McKinley et al. 2015). The core principle in citizen science datasets is to use a very simple standardized protocol replicated over various survey regions toward a broader conclusion (Devictor et al. 2010). Considering the wide spectrum of citizen science activities happening over a region, it is practically difficult to monitor their activities and authenticate the collected data. Hence assessing the level of interest shown by citizen scientists and analyzing their background knowledge and aptitude is essential to assess the reliability of their contribution to the project. Many citizen science programs have focused mainly on training the volunteers and validating their data with a scientific way of collection to streamline the data collection process. The lack of proper verification of the data generated through citizen science programs may impact their policy-oriented applications (Rowland 2012), hence also requiring a third-party audit of the data and associated outcomes.

Error and bias due to variation in observer quality

Despite the abundance of data produced and the numerous scientific breakthroughs that have resulted, professional scientists are sceptical about citizen science. This doubt may have its roots in the fact that citizen science is still not seen as a mainstream scientific approach (Theobald et al. 2015). Alternatively, some experts could think that unpaid participants aren't dedicated or competent enough to work at the same level as paid personnel. The ethics of working with volunteers have been questioned (Resnik et al. 2015), as have the "motivations and objectives" of the participants themselves (Show 2015), as well as their capacity to produce high-quality data (Hunter et al. 2013). Even research producing high-quality data might be challenging to publish in journals and is frequently confined to educational or outreach sections of the journals and conferences since citizen research is sometimes considered as dubious science (Bonney et al. 2014). Incorporating participants with different levels of understanding and expertise will result in measurements, such as the identification or enumeration of species, being less accurate. Additionally, the data may contain major sources of bias, such as under-detection of species or non-random distribution of effort (Crall et al. 2011). Opportunistic data are typically thought to represent the true distribution of species. However, it may not be entirely true. According to Johnson (1980), environmental factors that influence species occupancy are determined by a hierarchical selection process, whereas opportunistic data are biased because they depend on the presence of an observer and their capacity to spot and recognize the animal as well as record and submit the data. The areas the citizen scientists cover and those occupied by the species may not overlap completely. There are numerous methods to incorporate bias into a dataset, and determining the processes that contribute to bias is crucial to choosing the right analytical strategy (Bird et al. 2014). Taxonomic biases (Mair and Ruete 2016) and interobserver skill disparities (Kelling et al. 2015) are additional biases related to citizen science projects that can affect the validity or quality of the data (Gilfedder et al. 2019). Since the data quality supplied by citizen scientists has long been a concern, the biggest issue is the policy recommendations arising out of such studies (Dickinson et al. 2010, 2012).

Methods for improving data analysis for volunteer data

Issues like the aforementioned have prompted citizen science initiatives to improve sampling procedures and training, managing databases (Crall et al. 2011), and filtering or subsampling data to address inaccuracy and inconsistent effort (Wiggins and Crowston 2011; Wiggins et al. 2011). Data can also be grouped among species (Fithian et al. 2015), and supplemented with datasets with a predetermined sampling effort (Giraud et al. 2016) to maximize the accuracy of the information obtained. The bias and error concerns that frequently exist in Citizen Science data are not unique; similar challenges are present in datasets from a wide range of fields that can be solved by applying several analytical techniques. Models of species distribution can take into consideration variations in interobserver skill (Johnston et al. 2018). Alternately, sampling techniques and strategies can be improved (Bird et al. 2014), which would allow citizen science initiatives to transition from unstructured to more structured ones throughout the project (Kelling et al. 2018). Machine learning (ML) algorithms are available for complex datasets that can assess the relative contribution of numerous predictive variables to explain of the data collected (Hochachka et al. 2012). Before, during, and after data collection, potential sources of bias and error are reduced via data standardization, volunteer orientation, filtering, and validation methods (Wiggins et al. 2011). Studies that compare data produced by knowledgeable volunteers versus specialists frequently find similar estimates (Edgar and Stuart-Smith 2009). However, it can be challenging to adopt strict rules or get rid of all bias and error sources in many widely dispersed databases. Therefore, it is conceivable that global citizen science datasets may deviate from several fundamental presumptions of statistical studies.

Source of funding

Funding citizen science projects could be essential for better results and coordination among the volunteers. McKinley et al. (2015) report that an organization or project investigator must invest considerable time and money in citizen science projects to get the desired results. For instance, volunteers might not be willing to share the petty expenses involved in the project course. Any marine and coastal citizen science projects taken up would require the volunteers to travel extensively by road and boat, which is a challenge for implementation. Cigliano et al. (2015) report logistical support being a major challenge in marine and coastal projects requiring survey boats, diving gears, and transportation to the coast. Finding the right collaborators could also cut down the expenditures. For instance, scuba divers might regularly dive into selected places of interest. Their day-to-day routine activities are to be used for the citizen science projects, such as sharing photographs or any unusual observations of the coral reef health in the dived site. They can assist in sightings of marine mammals, locate specific areas where these mammals are spotted, or even spot rare and near-extinct marine faunal groups during their dives. Fishermen's services for involvement also won't cause additional expenses as sea travel is their routine activity for fishing. Involving students or the public could incur expenditure that needs to be met out. Addressing the issue of funding constraints and logistical supports are to be coordinated properly for successful citizen science programs.

Training needs of the volunteers

Training and capacity building were found to be a core part of the engagement in citizen science (Velde et al. 2017). The success of citizen science initiatives greatly depends on the quality of data collected by the volunteers. Several citizen science projects ensure that the volunteers were trained and assessed for the collection of quality data (Sherbinin et al. 2021). With proper training, the data collected by citizen scientists can be reliable and robust (Velde et al. 2017). The range of volunteers engaged in the citizen science projects can be either amateurs or an expert in their respective fields. Irrespective of their level of understanding, training, demonstration, and validation remain crucial parts of citizen science programs (Martin et al. 2016).

Infrastructure

Vattakaven et al. (2022) outline the importance of online and offline infrastructure that is required to manage project activities as the backbone of citizen science projects. Here the online infrastructure refers to the web/mobile-based tools that could support the project requirements, whereas offline infrastructure involves outreach activities through contacts and efforts. Designing a database based on web and mobile applications is much desired in places like Andaman and Nicobar archipelago, as data collection over a large-scale area is a practical issue through conventional data collection and reporting processes. Nowadays, internet services have greatly been developed in parts of the Island and hence adequate time should be spent on designing smartphone-based applications that could enable data collection and storage processes. Sufficient data collection and reporting trials should be undertaken to ensure that the data gathering and reporting process are free from errors or glitches. The researchers backing up the citizen science projects should also have adequate manpower to carry out these activities in the desired time frame. Data analysis, interpretation, dissemination, data storage, and further use of data require

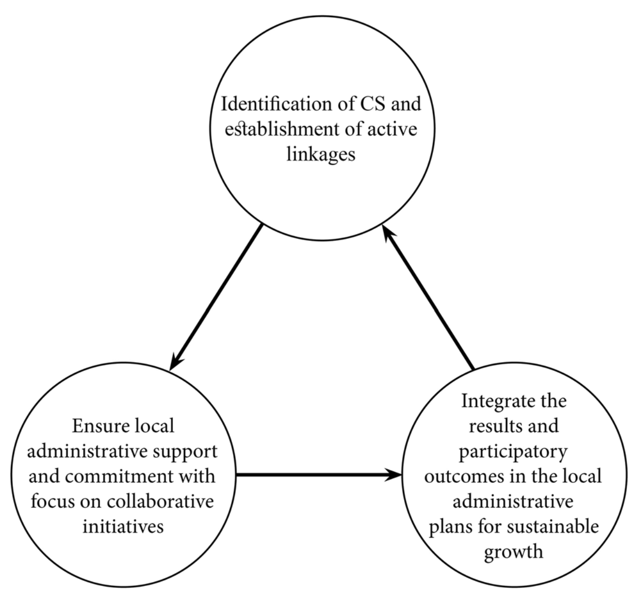

Fig. 3 Key strategies for implementing citizen science in the Islands

a robust infrastructure that should be planned properly for successful outcomes (Wiggins et al. 2011).

Linking citizen science with environmental programs

Stakeholder engagement is the most crucial component in conservation and management programs (Gray and Scyphers 2017). Environmental protection groups have taken part in citizen science programs over several decades to protect our environment (Rubio-Iglesias et al. 2020). It is of profound importance that citizen science projects should be properly linked with environmental protection agencies so that the data generated can be applied in policymaking and decision-process. Environment protection agencies in the United States and Europe were actively making use of citizen science in their decision-making process (Owen and Parker 2018). The key advantage of citizen science is that it can gather an exponential volume of data in time and space (Cigliano et al. 2015). However, the real challenge lies in the transformation of such data into action through policy and the decision-making process. To achieve such a process, the policymakers and environmental managers must be linked and involved in citizen science projects from inception. The process to be adopted for such management is shown in Fig. 3. In an environmentally fragile archipelago like Andaman and Nicobar, the role of environmental agencies and Government departments in the successful implementation of citizen science is essential. Their engagement should be strengthened further through collaborative efforts to achieve the desired goals. The data generated through citizen science could provide useful insights into the health of the coral reef ecosystems, strengthening the monitoring of mangroves, location of seagrass beds, the hotspots of debris accumulation, invasion of alien fishes, sighting of marine mammals, etc. Once we garner sufficient data validated through scientific studies, the results generated must be transformed into application-oriented aspects. Otherwise, the data generated will not have any application in the policymaking process. Hence the success of citizen science in policymaking and decision process lies in strengthening the collaborative initiates in citizen science activities. Local government and administrative authorities being the policymakers or custodians of biodiversity must be involved in every phase of the project right from conception to dissemination of results. For instance, the Ministry of Environment, Forests and Climate Change, India, plays a key role in governing the coastal ecosystems such as coral reefs, mangroves, and seagrasses as they fall under ecologically sensitive zones (MOEFCC 2019). Large-scale data generated from these ecosystems can provide crucial insights into strengthening the management mechanism. To strengthen the collaborative network, officials from such departments should be engaged in citizen science activities and the data generated must be shared on a time-time basis.

Drivers for volunteer participation

Citizen Science programs can be successful only when citizens readily agree to participate in them. Since they aren't professionally involved in research, there could be a lack of interest. Targeting the right audience is key to the successful execution of the programs. Introducing programs in schools to use citizen science-based projects as a part of their curriculum would create an influx of a lot of participants. Even though different tactics can be applied to motivate citizens to participate in such programs, the biggest driver is interest. Citizen science projects carried out by Kelly et al. (2019) suggested that participants in the programme were enthusiastic to contribute to scientific research and learning. The participants were driven by the ideals of working toward better research prospects (Kelly et al. 2019). Conflicts in the different community groups that are targeted in the programs must also be able to work in harmony with each other; conflicts between parties may cause hindrances in the active participation of certain groups that are crucial for studies. Divers and fishers in some places do not see eye to eye (Kelly et al. 2019), and if they keep their disagreements aside, and can communicate more effectively with one another, they may support more thoughtful, developed, and futuristic discussions for marine management programs (Boutilier 2014). To attract new participants, one strategy to promote stakeholder interactions through citizen science is to draw on already established networks within project communities, such as diving and fishing clubs, tackle shops, etc. (Haywood 2015). Participants in citizen science programs are known to share the knowledge they get from their experiences, and many plans to change their behaviour because of what they learn (Nursey-Bray et al. 2018).

Failures in citizen science

In a study, Druschke and Seltzer (2012) developed a streamlined technique for gathering bees in coloured bee bowls and managing them in the lab, while working on the project design with a bee specialist and then developed a straightforward collection methodology and an instructive booklet for the participants. The research team created a species list for the Anthophila in the Chicago area based on the findings gathered by the citizen scientists. However, they learned that the participants did not meet the knowledge, attitude, and behavioural goals they had hoped for thorough surveys taken before and after the program. They found out that the participants were unable to accomplish these objectives because they were unable to successfully involve the citizen scientists in the research project. The ever-increasing popularity of citizen science would certainly result in errors and blunders, and hence it is of absolute necessity to adopt proactive strategies for preventing such failures. The inter- and even transdisciplinary techniques used in citizen science projects make them frequently difficult and complex tasks for laypersons to grasp (Westreicher et al. 2021). In a study conducted by Westreicher et al. (2021), 55% of the reported failures had to do with poor communication and challenging assignments. For a successful citizen science project, the administration of accurate in-person communications is crucial. After the conclusion of any citizen science project, discussing the failures that came across during the study may be very instructive, useful, and beneficial for individual academic careers. It may also serve as a guideline for other initiatives that would prevent repeating the same errors (Westreicher et al. 2021).

Future directions

Climate change impacts such as increased ambient temperature, sea level rise, increased atmospheric carbon dioxide, and other extreme events are predicted to impact the coastal wetlands (Ross and Adam 2013; Michener et al. 1997; Blankespoor et al. 2014). The challenges foreseen ahead are to be faced with innovative approaches and the review accordingly outlines the relevancy of citizen science. The archipelago of Andaman and Nicobar is known for its diverse coastal wetlands and its vulnerability to natural and anthropogenic impacts. Given the diverse challenges confronted by the fragile coastal wetlands of the islands, citizen science projects could be a potential tool in managing the coastal wetlands for sustaining the long-term benefits and ecosystem services provided by these coastal wetlands.

Conclusion

Citizen Science is an up-and-coming tool that has tremendous potential if used beneficially. Local citizens are a reservoir of knowledge passed down from generation to generation and we can aim to make use of this knowledge for various scientific purposes. ANI are home to several tribal communities that have lived for many years without advanced technologies. Such profound knowledge of the natural ecosystems is important to be recorded to prevent it from fading away. Since conservation challenges are directly linked to human behaviour, citizen science is the more reasonable approach as it offers an efficient yet cost-effective way of obtaining comprehensive datasets over large spatial scales. If the basic constraints are somehow overcome, citizen science will help revolutionize the academic scene for the better.

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Data availability All the data and relevant information are provided in this review article.

Declarations

Conflict of interest The author declare that they do not have any competing interest.

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