Table of Contents

Chapter 1 - Indigenous Knowledge and Culture

Chapter 2 - Communities and Values

Chapter 3 - History and Change in Moreton Bay

Chapter 4 – Water Quality, Land-Use and Land-Cover

Chapter 5 - Habitats, Biodiversity and Ecosystem Function

Chapter 6 - Citizen Science

Chapter 7 – Industry and Planning

Chapter 8 – Moreton Bay Marine Park

Appendices

Maps of Moreton Bay and catchment

Citizen science photographic identification of marine megafauna populations in the Moreton Bay Marine Park

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Abstract

Marine megafauna such as cetaceans, sea turtles and elasmobranchs attract considerable public attention. Despite their popularity relatively little is known about their populations in Australia. This is due to inherent challenges faced in researching megafauna in the wild, including the difficulty of locating and tracking species, their often remote distribution and elusive nature. The advent of photo identification techniques and the engaging of citizen scientists have contributed to research outputs and increased general understanding of many marine megafauna populations. We present three case studies about how citizen scientists contribute to research in the Moreton Bay Marine Park: 'Project Manta';'Grey Nurse Shark Watch'; and 'Dolphin Watchers'. Based on our comparative assessment of the case studies we identify several benefits of using photo identification (photo-ID) techniques on marine megafauna for this region. These include: (i) the extra data provided by citizen scientists substantially **increases research effort** and coverage in time and space; (ii) citizen scientists are self-funded or funded through tourism programs and substantially **reduce the costs of data collection** for research while supporting local tourism ventures; (iii) citizen science programs help disseminate research results to participants through increased contact with researchers, thereby **increasing public education** outcomes; and (iv) citizen science programs have had tangible downstream **outcomes for conservation efforts** including participation in stakeholder groups, data being used for threatened species assessments, and monitoring of sick and injured animals over time. We identify several challenges with marine megafauna citizen science programs including: (i) raising awareness of projects and accessing photos; (ii) limitations of image-matching

software; (iii) development of online database structures that are transferable across projects; (iv) maintaining engagement with public participants; and (v) long-term funding. We make recommendations to address these challenges and propose future directions to improve citizen science programs in the region.

Keywords: photo-id, reef manta ray, cetacean, bottlenose dolphin, humpback dolphin, grey nurse shark

Introduction

The Moreton Bay Marine Park (MBMP) contains diverse and abundant marine megafauna, including marine mammals, elasmobranchs, and sea turtles. A subtropical embayment (1), Moreton Bay and its adjacent reefs which comprise the marine park host a range of substrates and bio-regions that provide habitat to a distinctive assemblage of resident and transient megafauna. Resident marine mammal species include: the Indo-Pacific bottlenose dolphin (*Tursiops aduncus*); the most southerly population of dugongs (*Dugong dugon*) on the east Australian coastline (2); and the recently-described Australian humpback dolphin (*Sousa sahulensis*) (3). Transient cetaceans include several whale species, the most conspicuous being the humpback whale (*Megaptera novaeangliae*), which has a seasonal migration that passes mostly within 10 km of Point Lookout, North Stradbroke Island (4). The Bay is an important feeding ground for all six species of sea turtles inhabiting Australian waters (5). It is also home to a diverse assemblage of resident and transient shark and ray species, with shallow habitats providing refugia for resident elasmobranchs as well as important nursery grounds for migratory species (6). Offshore rocky reefs are visited by seasonally transient species, including reef manta rays (*Mobula alfredi*) (7) and leopard sharks (*Stegostoma fasciatum*) (8) that have southerly range-extensions during summer and autumn coinciding with the strengthening of the warm East Australian Current. By contrast, more temperate species such as the white shark (*Carcharodon carcharias*) migrate north and into the Bay as southerly waters cool during winter and spring, whereas the grey nurse shark (*Carcharias taurus*) uses the MBMP waters year round with numbers peaking throughout winter and spring (9, 10).

The MBMP is adjacent to the rapidly developing urban hubs of South East Queensland. Human activities in the region have had pronounced impacts on the Bay through: nearshore habitat loss; declining water quality from pollutants; sedimentation; and increased boating and fishing (2). Given that these pressures are ongoing, it is important to assess and understand their potential impacts on marine megafauna within the MBMP.

Obtaining data on large marine animals can be challenging because of their elusive behaviours, sparse populations and wide ranging habitat preferences (11). As many species of megafauna are considered ‘threatened’, it is preferable to collect data using minimally-invasive approaches. Photographic identification (photo-ID) is one such method for tracking individual animals based on unique body patterns (12). Photographs of animals showing identifiable patterns that are stable over time provide information about when and where an individual animal was sighted. Photo-ID studies in the ocean initially focused on marine mammals (13). They have rapidly expanded to incorporate fin shapes and body patterns in other groups including sharks (36), rays (12), sea turtles (14) and bony fishes (15) (see examples for case studies: Fig. 1). Photo-ID methods have been used to: examine patterns of site-fidelity to, and movement between, key habitats (7, 10); resolve biological parameters such as reproductive periodicity (16); identify behaviours including social interactions with conspecifics (17); and estimate population size and other demographic parameters (18).

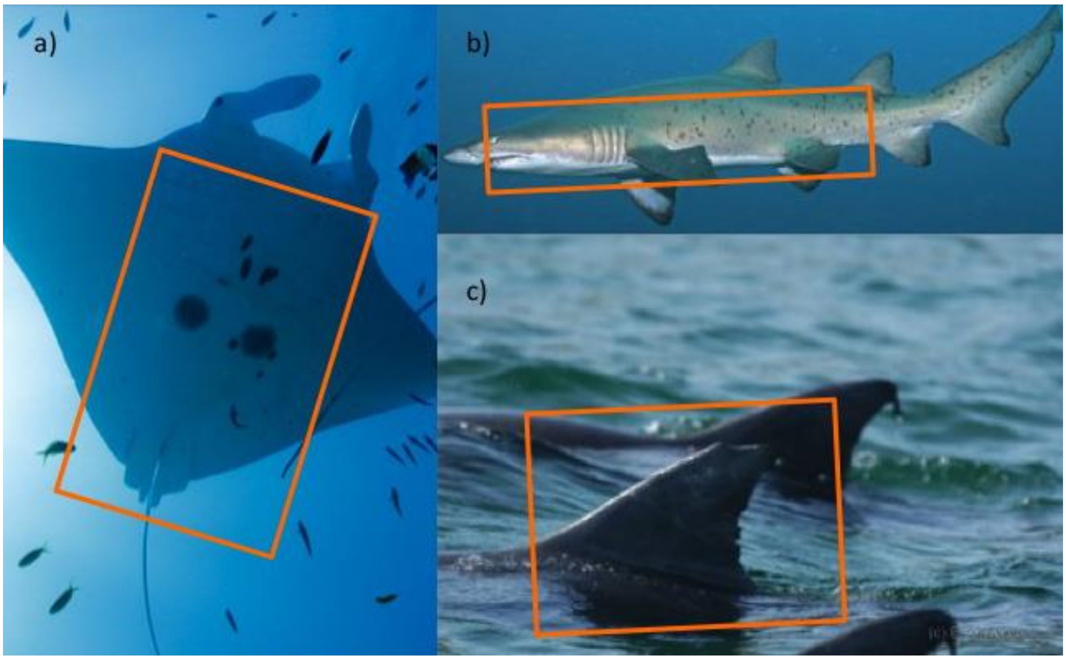

Figure 1. Representative photo-ID images of the three case study species. Orange boxes highlight the areas for identification of the: (a) reef manta ray, (b) grey nurse shark, and (c) Australian humpback dolphin.

With the increasing accessibility of digital camera technology, the past decade has seen more citizen scientist involvement in marine photo-ID projects. This contributes to knowledge acquisition while simultaneously educating participants and increasing awareness. Programs that involve citizen scientists range from opportunistic sighting reports to highly structured, hypothesis-based research projects (19). Citizen scientists generate important data for studies on distribution, movement and abundance of large, mobile species such as bottlenose dolphins (*Tursiops* spp.) (20). Mark–recapture population size estimates based on citizen science data have shown strong congruence with results from dedicated researcher surveys for whale sharks (*Rhincodon typus*) in the Maldives, indicating that citizen science data can be suitable for estimating abundance (21).

Citizen science programs are hosted by non-government organisations, universities, businesses and government agencies. These programs are motivated by the need to connect the public with science, increase conservation awareness, and encourage environmentally-beneficial behavioural change (19). With the growing challenges of funding research, projects are increasingly reliant on the participation of citizen scientists as a cost-effective option (19). In some cases, fee-based citizen science programs are embedded in the expanding voluntourism industry (e.g. Earthwatch) and contribute financially to research (22).

Several photo-ID studies within the MBMP have estimated population sizes for various dolphin and shark species (18, 23, 24). While these studies used a dedicated researcher survey approach, Couturier et al. (2011) also combined citizen science surveys with those of researchers to investigate movements of reef manta rays along the east Australian coast (7). There are now several ongoing megafauna photo-ID studies in the region that incorporate citizen science contributions of photographs, including 'Project Manta', 'Grey Nurse Shark Watch', 'Dolphin Watchers', 'Humpbacks and Highrises' and 'Spot the Leopard Shark'. Here we present three case studies from the MBMP that demonstrate different ways of using citizen scientist contributions in marine megafauna research programs. We discuss benefits of the approaches used, challenges faced, and recommendations for the future.

Case studies

Project Manta

Project Manta is a multidisciplinary research collaboration[1] investigating the population biology and ecology of reef manta rays (*Mobula alfredi*).

The project has four main aims:

- investigating connectivity and movement between populations within Australian and neighbouring waters;
- estimating population size and variation through time;
- understanding biological and environmental drivers of population dynamics; and
- providing management recommendations for populations in the region.

Reef manta rays are listed as 'Vulnerable' on the IUCN Red List of Threatened Species (25). They are captured at multiple locations around the world as target species for their gill rakers and flesh, and as bycatch. As they are slow growing, late to mature and have low reproductive output, they have low recovery potential from exploitation (26). These conservation concerns have spawned research efforts at manta ray aggregation sites globally. These multiple citizen science projects collect data about these rays to feed into larger research initiatives such as those led by Manta Trust, Marine Megafauna Foundation and Project Manta.

Individual manta rays are born with a unique 'spot' pattern on their ventral (belly) surface that is retained throughout life, enabling individual identification (Fig. 1a) (27).

[1] Collaborators and participants can be found on the Project Manta website at https://biomedical-sciences.uq.edu.au/project-manta

Many manta rays aggregate seasonally in particular locations. While feeding at the surface or visiting 'cleaning stations' they are easily approached by breath-hold or scuba divers. This provides opportunities for underwater photography of the manta rays, and engages tourism operators and the public in scientific research.

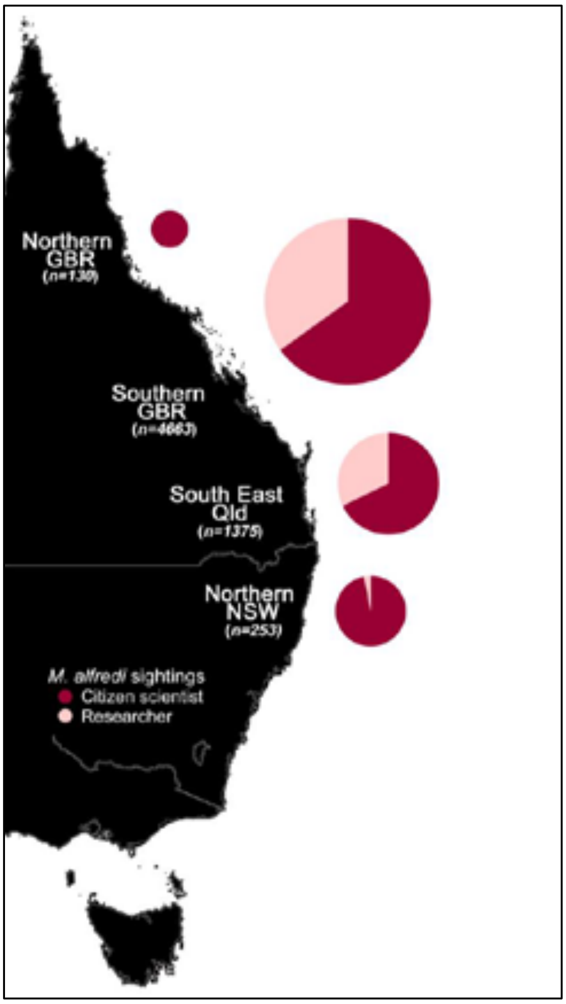

Figure 2. Proportion of reef manta ray (*Mobula alfredi*) sightings along the eastern Australian coast contributed by citizen scientists and researchers. Pie chart size represents relative number of contributions at different locations. GBR – Great Barrier Reef, Qld – Queensland, NSW – New South Wales.

Research groups use photo-ID of manta rays to investigate biological characteristics such as reproductive periodicity and behaviour (16) and to estimate population size (28, 29, 30). Public submission of images to the web has been invaluable in generating large photographic catalogues of manta ray individuals, increasing our ability to examine aspects of their ecology such as movement patterns among sites (7).

Since Project Manta began in 2007, its citizen science program has contributed photo-ID records of reef manta rays along the east coast of Australia. As of November 2017, over 1200 individual reef manta rays had been identified from 6380 records with 65% of individuals being sighted on more than one occasion. Citizen scientists have provided the original photographic record for approximately 67% of the manta rays, as well as 53% of the re-sighting records (Fig. 2). Along the Australian east coast, the reef manta ray is distributed from the Torres Strait in tropical Queensland to the South Solitary Islands, NSW. The MBMP contains 'Manta Bommie', a key reef manta ray aggregation site in the southern half of its range, located offshore from Point Lookout, North Stradbroke Island. Around 20% of the photographic contributions to Project Manta come from 'Manta Bommie'. Citizen science contributions to the Project Manta photo-ID database have assisted with identifying manta ray aggregation hotspots in eastern Australia, obtaining baseline population numbers, as well as demonstrating seasonal movements of individuals between the MBMP and Lady Elliot Island on the southern Great Barrier Reef (7).

Public participation in Project Manta is encouraged through an online presence, personal interaction with dive centres, advertising material (including promotional stickers and posters), and by disseminating results using posters and web-sites. In particular, Manta Lodge Scuba Centre on North Stradbroke Island organises twice-yearly 'Manta Fest'; a scuba-dive festival run over two weekends during the manta ray aggregation period, and contributions of images to the citizen science program is encouraged. Researchers attend the festival to give educational presentations about Project Manta, demonstrate to divers best practice underwater interaction and encourage diver participation in data collection.

Various incentives encouraged citizen science participation in Project Manta, including:

- a well-maintained and regularly-updated social media presence (Twitter, Facebook with >15,000 followers, email newsletters);
- manta ray 'naming rights' for participants who discover an animal new to the database;
- Project Manta branded t-shirts awarded for major contributions, such as provision of large numbers of photographs or important historical photographs; and
- social media competitions such as the one held to identify the 1000th manta ray for the east Australia database.

A regular media presence has also increased the project's profile. Press releases on research findings, including quality imagery and video, have ensured high levels of uptake by media outlets domestically and internationally. Appearances in high-profile documentaries (e.g. David Attenborough's BBC Series 'Great Barrier Reef' and Nat Geo WILD's 'Manta Mystery') have also provided an avenue to attract prospective citizen scientists. Following each new documentary's premier there is a spike of hundreds of new followers on the social media page. These strategies have been integral to maintaining a public presence in the citizen science space to encourage participation in the project and generate greater awareness and understanding.

However, the success of the citizen science aspect of Project Manta presents a major challenge. Comparing and matching individual images to those in the master database is time consuming. There are a number of computer programs, including MantaMatcher (31), that automate image-matching using specialised algorithms. However, the successful matching of images using this software is often hindered by poor image quality. Consequently, a large number of images require matching by eye, necessitating a dedicated part-time project officer to manage the citizen science program, maintain community engagement, and educate new project participants about types of images suitable for manta ray pattern recognition. Other specialised software is used to identify key features on a manta ray (32), speeding up manual identification.

In conclusion, the contribution of citizen science to Australian manta ray research has been invaluable. Citizen scientists extend the coverage in time and space of the Project

Manta research trips that are limited to a few key aggregation sites each year. Public contribution of archival images, some taken decades ago, help Project Manta investigate important questions about longevity, changes in habitat use and population structure. Engaging with citizen scientists has also provided an ideal platform for disseminating research findings to a broad audience.

Grey Nurse Shark Watch

Grey Nurse Shark Watch (GNS Watch) is a citizen science research and community education program that aims to improve the conservation management of the Critically Endangered (IUCN Red List, (33)) grey nurse shark (*Carcharius taurus*) in Australia. Historically, grey nurse sharks were hunted for their oil, flesh, skin and fins, and were the target of recreational fishers (34). Although protected in Australia, they remain threatened by ongoing incidental capture in recreational and commercial fisheries, as well as shark control programs. Information on population size and trends is necessary for their effective management (35, 36).

GNS Watch, including the database, webpage and Facebook page, was launched in 2011 and is hosted by Reef Check Australia. Citizen scientists contribute photographic records of grey nurse sharks to research projects to address six of the ten objectives of the 2014 National Recovery Plan for this species:

i. to monitor numbers of the Australian east coast population of grey nurse shark and determine its trend;
ii. to provide information on distribution and movements at different stages of grey nurse shark life history;
iii. to provide data to quantify interactions with commercial and recreational fishing gear, along with associated injuries and recovery;
iv. to identify new aggregation sites;
v. to increase public awareness; and
vi. to provide accurate data for management.

Individual grey nurse sharks can be identified by unique spot markings on their flanks (Fig. 1b) as well as any other key identifying features (e.g. jaw wounds, missing fin sections). Photographs of grey nurse sharks are taken during biannual surveys (January to February and July to August) and opportunistically throughout the year at several aggregation sites along the Australian east coast. The biannual surveys accounts for the seasonal variation in their distribution and movement patterns (10).

GNS Watch uses a variety of training materials and methods to educate volunteers and to help ensure that photos suitable for photo-ID are taken without disturbing the sharks. Volunteers who participate in scheduled surveys read the ‘Volunteer Methods Manual’ and to view the ‘GNS Watch Volunteer Training Video’ prior to undertaking surveys. In addition, several divers are trained each year at the annual ‘Shark Fest’ scuba diving festival on North Stradbroke Island, and additional training sessions are conducted as required. Most volunteers that contribute to scheduled surveys are ‘regulars’ who are very experienced and communicate regularly with the GNS Watch team. This helps to maintain a level of consistency in survey effort between volunteers during scheduled survey periods.

GNS Watch project officers match images to those already in the database by using ‘key identifying features’, returning a subset of existing identified sharks. If a match is not found, the shark is checked by eye against the full catalogue for that particular sex, size and view orientation (e.g. left side of the body photos of all mature male sharks). The online database provides key summary results for reporting (e.g. the maximum number of sharks counted during a survey period or year). Mark–recapture analysis is used to assess population trends. Each month, GNS Watch posts an article on their Facebook page and a story in the Reef Check Australia E-newsletter. Targeted public engagement prior to and during the biannual surveys includes:

- at least two public presentations to dive clubs/shops;
- additional Facebook posts (>1160 followers) and website updates;
- emails and distribution of printed education materials and dive slates to dive businesses, clubs and key volunteers; and
- prizes awarded to several survey participants and volunteers publicly recognised within six weeks of each survey period.

Since the start of GNS Watch in 2011, over 600 registered members have conducted 40 surveys at key locations at regular intervals, and 66 opportunistic surveys. Over 6500 photographs have been submitted to the project of which 3822 are approved photographs for the database, based on appropriate metadata, clarity and orientation of the shark. At least, 1271 individual sharks have been identified from these photographs comprising 168 sharks identified from both sides plus 539 females and 564 males identified by their right side only. The number of sharks identified by their left side only was slightly less with 529 females and 508 males. The sex ratio in all photographic categories was almost even. Of the 168 sharks identified from both sides, approximately 80% have been sighted on more than one occasion. In contrast, for the sharks identified from one side only, approximately 25 to 27% have been sighted on more than one occasion. The field methods encourage photographs to be taken of both sides of each grey nurse shark and it is therefore probable that individuals are represented in the database by both their left and right sides. However, it is very difficult to match them as the markings are not identical on both sides. One example of how a shark can be matched to its left and right sides is when features such as dorsal or caudal fin damage have been photographed from both sides during a dive.

GNS Watch faces several challenges. First, considerable time is spent applying for funds and investigating fundraising opportunities to cover costs of the webpage, interactive database, online photo-library, and a program coordinator. Second, it is time consuming to train and retain volunteer project officers to assist with processing the photographs and other behind-the-scenes program outreach. The consequent delay to disseminating results can lead to disengaged volunteers. Third, poor weather conditions can reduce survey coverage and affect survey timing. Lastly, volunteer divers do not visit some critical grey nurse shark aggregation sites during scheduled survey periods. GNS Watch encourages diving at these sites by offering prizes or relying on research divers or partners such as Sea World, Underwater World, and state government agencies.

Despite these challenges GNS Watch has proved to be a successful partnership between researchers and citizen scientists that generates important data for assisting with the recovery of the grey nurse shark along the east coast of Australia. Citizen science contributions include identifying new grey nurse shark aggregation sites. This information is provided to relevant researchers and management agencies to facilitate further investigation about the importance of aggregation sites to the population. Citizen scientists also report on and provide photos of grey nurse sharks with retained fishing gear and in some instances morbidity is probable without intervention. GNS Watch liaises with the relevant conservation management agency (i.e. Queensland Parks and Wildlife Service) and Sea World to attempt rescue and rehabilitation. Subsequent photographic contributions by citizen scientists of these sharks help to inform all partners and the community about the sharks' condition, movements and reproductive events post intervention (i.e. mating and pregnancy).

Dolphin Watchers

Dolphins and whales (cetaceans) are iconic marine megafauna that attract considerable public attention. Cetaceans play vital ecological roles as high-order predators and are under pressure from numerous human activities. Species with locally-resident populations that inhabit coastal zones and estuaries adjacent to urbanised centres, such as Moreton Bay, are among the most vulnerable to human activities resulting in pollution, encroachment, boat strikes and other disturbances (24, 37). These include the Indo-Pacific bottlenose (*Tursiops aduncus*) and Australian humpback dolphins (*Sousa sahulensis*). Cetacean research surveys are expensive and detection rates are typically low, so citizen scientists play a vital role in filling knowledge gaps about population sizes through their sightings (19).

'Dolphin Watchers' is a program of Dolphin Research Australia Inc., a not-for-profit marine conservation, education and research organisation. This program was initiated in 2009 to provide opportunities to engage, connect and empower the public to assist in the conservation of regional dolphin populations and support research efforts. The program entails: (i) opportunistic sighting reports from the public; and (ii) broad-scale land-based observation surveys with trained volunteers. The latter has been established in the Northern Rivers of NSW and during 2015to 16 engaged 15 volunteers in monthly land-based surveys. Dolphin Watchers also offers an 'eco-volunteer' program with the Moreton Bay Dolphin Research Project. This is a fee-based program whereby volunteers are trained to participate in hypothesis-driven research during intensive annual surveys.

Photographs of dolphin dorsal fins are used to identify individuals from the patterns of nicks and notches on the trailing edge that create a 'natural tag' (Fig. 1c) (13). Photo-identification of individuals from opportunistic sightings and dedicated surveys enable estimates of the population abundance, trends and status, along with individual life histories, movement and residency patterns. As part of the opportunistic sighting reports contributed to Dolphin Watchers' online platform, members of the public are encouraged to report the location, behaviour, species and photographs of dolphins observed during their marine-based leisure activities (38). Between 2012 and 2015, over 263 opportunistic sighting reports of dolphins from around Australia were received from 34 people through the online reporting platform. Twenty percent of these sighting reports included photographs and four reports included images for photo-ID.

Despite the limitations of opportunistic sighting data of cetaceans for inferring demographic and ecological parameters (39), there are numerous benefits to collecting these data through citizen science. These include establishing baseline information, identifying previously unknown populations, reporting unusual behaviours, and attaining information about the welfare and health of injured, entrapped or stranded individuals.

Dolphin Watchers promotion has focused on southeast Queensland and northern New South Wales to coincide with Dolphin Research Australia's long-term research projects in Moreton Bay and the Gold Coast, Queensland, and Tweed Heads and Byron Bay in New South Wales.

Public participation in the project is encouraged through various methods including:

- specialist training sessions;
- multi-media promotions through press releases, social media (> 2000 Facebook followers) and advertising (e.g. leaflets and posters); and
- direct community outreach through market stalls in target areas.

Although promoting Dolphin Watchers has resulted in a steady stream of opportunistic reports, there have been numerous challenges. The most prominent are: maintaining public engagement and interest; allocating organisation resources (including volunteers to handle reports); funding to continually promote the program; and acquiring quality sighting information (including photographs).

As human populations and demands on coastal zones increase, pressures from human activities on coastal dolphins are expected to intensify. Citizen science programs assist in knowledge acquisition and monitoring the status of dolphin populations. Such programs also promote and advocate for environmentally positive behavioural change in participants by providing experiences that can incite a sense of stewardship and meaning to participants. This in turn leads to increased conservation awareness and protection of vulnerable populations such as those in Moreton Bay.

Discussion

Citizen science contributions to photo-ID studies in the Moreton Bay Marine Park have and will continue to contribute to monitoring marine megafauna populations. However, developing citizen science programs poses several challenges.

i. **Engaging the public and accessing photos.** Each project has to independently develop its online and print-based engagement pathways. Each project has different means of contributing photographs including email, Facebook and directly on USB sticks.
ii. **Limitations with photo-ID matching.** Photographs provide useful data, but can be time consuming and difficult to match. Automated software options are available, but suffer from false negatives (real matches are not identified) and are generally unable to cope with wide ranges in photo quality. Volunteers are often sought to assist with photo-ID matching, but considerable training is needed and it can be tedious work that volunteers tire of easily.
iii. **Database limitations.** Most databases for photo-ID collection are custom made to facilitate the research, but are generally difficult for other researchers or interested parties to access.
iv. **Maintaining engagement with the public.** Engagement is time consuming and the lag between public contributions and the longer-term scientific outcomes makes it challenging to maintain motivated volunteers.
v. **Long-term funding.** While citizen science projects can reduce costs associated with data collection, there are still considerable costs including advertising, training and organising volunteers, online presence, data processing, and disseminating findings through public outlets. A critical role that requires funding across citizen science programs is that of project coordinator. Traditional scientific funding sources are not always amenable to funding such costs.

Based on the comparative analysis of case studies, there are several recommendations that help to ensure active and effective citizen science programs.

i. **Improve networking** – create centralized websites, social media outlets and advertising material to enable participants to learn about the suite of citizen science projects and potential contributions. Many citizen scientists have photographs to contribute for more than one target species but may be unaware of the full range of applicable projects. A central platform for photo-ID projects would produce an economy-of-scale, enabling a greater reach for individual projects to engage new participants cost effectively, as well as disseminate findings.
ii. **Develop online photo-ID encounter databases** – a generic platform could be adapted to specific requirements for each study. Enabling search functions so participants can find their personal sightings would engage the public and help disseminate results. GNS Watch is an example of a project with such an online database, although this was developed at considerable cost, and was not designed with other photo-ID projects in mind.
iii. **Create funding consortiums** – strategies to promote philanthropic donations to citizen science projects to assist with running costs could be centralized. Centralized campaigns could sell merchandise, organize joint voluntourism

trips, and target fundraising (such as 'Adopt a …' campaigns targeted over Christmas) and so raise revenue for multiple programs. Centralised consortia could also support and promote long-term industry interactions.

While each species has unique requirements, there are commonalities across the case studies that highlight several benefits of citizen science:

i. **Increasing research effort.** Research surveys only capture a small portion of patchy marine megafauna populations. Extra data provided by citizen scientists substantially increase data collection and coverage in time and space.
ii. **Reducing research costs.** Boat and scuba diving-based field-work for marine megafauna is expensive. Citizen scientists are self-funded or funded through tourism programs. This substantially reduces data collection costs and also supports local tourism businesses.
iii. **Increasing public education.** Citizen science programs help disseminate research results to participants through continual interaction with researchers. This is also of benefit to researchers, as funding bodies now typically request that results are disseminated more broadly than through specialist journals.
iv. **Tangible impacts of research and outcomes.** Citizen science programs on marine megafauna in the MBMP have had tangible downstream outcomes for conservation efforts. These programs have engaged a wide-range of stakeholder working groups, as well as informed conservation assessments, recovery plans or zoning reviews. For instance, GNS Watch is a key contributor to the grey nurse shark stakeholder group, who collectively supported the recovery plan review process and wrote to all relevant state and federal ministers providing their recommendations for the conservation management of this critically endangered species. Citizen science contributed to the revised classification of manta rays as 'Vulnerable' on the IUCN Red List (25, 40) and their inclusion for trade restrictions under CITES Appendix II listing (41). Trained volunteers and program coordinators distribute and discuss codes of conduct or legislative requirements to field volunteers, tourism operators and more widely to the public outlining behaviour that minimises disturbance to the animals. Photographs have enabled monitoring of sick or injured animals. Our local megafauna citizen science programs also play an important role in engaging citizen scientists and educating the broader community. They deliver numerous talks and distribute updates and educational material online and through other media about the importance of conserving these ecologically and economically important megafauna.

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