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SCUBA divers above the waterline: Using participatory mapping of coral reef conditions to inform reef management

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ABSTRACT

Coral reefs provide important ecological services such as biodiversity, climate regulation, and cultural benefits through recreation and tourism. However, many of the world's reefs are declining, with Caribbean reefs suffering a significant decline in living corals over the past half century. This situation emphasizes the need to assess and monitor reef conditions using a variety of methods. In this study, a new method for assessing reef conditions to inform management using participatory mapping by coral reef "experts" in the U.S. Virgin Islands (USVI) is described. Occupational SCUBA divers were recruited (n=87) to map coral reef conditions, uses, and threats (stressors) using an internet-based mapping website. The data reveal an uneven geographic distribution of reef conditions in the USVI with the most frequently mapped perceived healthy reef characteristics being: large amount of physical reef structure (n=872 markers); endangered or threatened species present (n=721); and large amount of live coral cover (n=615). The greatest perceived threats were: invasive species (n=606); water pollution (n=234); and unsustainable fishing (n=200). Areas of important reef characteristics, perceived threats to reefs, and perceived recovery potential were plotted to identify areas requiring critical management attention. The authors found that perceptions of healthy reef conditions outnumbered perceptions of reef threats for nine of the ten most familiar coral reefs; the most frequent activity type within the coral reefs was tourism diving; and for the most familiar coral reefs, the divers perceived a high recovery potential. Given the novelty of participatory mapping methods to assess coral reefs, the strengths and weaknesses of the method is evaluated. The authors further propose a management typology for categorizing reef areas to inform their future management. In the absence of primary data, or, as a supplement to underwater surveys and remotely-sensed data on reef condition, participatory mapping can provide a cost-effective means for assessing coral reef conditions while identifying place-specific reef locations requiring management attention.

1. Introduction

Coral reef ecosystems in the Caribbean provide a range of valuable services to people, including reef-related tourism and recreation (e.g., SCUBA, snorkeling, and recreational fishing), commercial fishing, coastal amenities related to real estate, and protection of the shoreline from storms [2,15]. However, long-term monitoring data indicate that Caribbean reefs are in decline, as evidenced by substantial reductions in live coral cover and key herbivorous species (i.e., sea urchins and parrot fish), coupled with concomitant increases in the number of reefs dominated by macroalgae [27]. In the U.S. Virgin Islands (USVI), scientific assessments have confirmed declining trends in overall coral reef health [12,28] both inside and outside marine protected areas [36]. This decline has resulted from a number of enduring, cumulative, and interacting factors, including inadequate land use planning, non-sustainable exploitation of marine resources, and significant natural events such as hurricanes and mass coral bleaching [38]. According to [27], without intervention, coral reefs in the USVI could become

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"ecologically extinct" within the next decade given current trends. The term "ecologically extinct" means that coral reefs would "no longer play any significant ecological role in determining the distribution and abundance of surviving species" ([27], 76) Impediments to improving the management of coral ecosystems include both a lack of actionable information about the status of reefs as well as their relative importance to the local community [42]. Without this type of information, resource managers are challenged to effectively prioritize competing management objectives in a fiscally limited environment.

Coral reef ecosystems have historically been monitored via the collection of data characterizing habitat features and the physical environment, as well as the presence and absence, abundance, composition, and distribution of key plant and animal species. Commonly, marine habitat and biological data are gathered using in-water surveys by research divers who systematically record data on coral reef features and species ([26,31,35]). Data on the status of commercially-important species, such as finfish, are also collected through fishery-dependent monitoring programs. Data on physical features and processes, such as water chemistry, water temperature, and currents are gathered manually with sampling or through the use of in-water automated or remote sensing technologies, such as buoys, remotely operated underwater vehicles, aerial photography, or satellite imagery [19,32]. Monitoring data are generally collected over time, enabling longitudinal analysis of coral reef communities and processes. However, scientific monitoring programs can be expensive or impractical for jurisdictions having significant reef areas spanning vast geographies [27].

In general, scientists are recognizing the value of connecting local ecological knowledge (LEK) of systems with data collected through the western scientific tradition, particularly in marine ecosystems [3,10,14,25,41,43]. To this end, scientists and resource managers have increasingly recruited SCUBA divers to collect data to improve understanding about the status of marine resources. Lorenzo et al., [30] collected information from recreational divers related to habitat quality, along with the distribution, status, and threats to endangered red coral. They concluded that information provided by divers was valuable for monitoring the status of the species over a broad geographic range. Goffredo et al., [22] relied on data collected by recreational SCUBA divers to aid in the assessment of seahorse (*Hippocampus* spp.) populations. Taylor et al. [41] and Forrester et al. [20] each surveyed divers to document trends in species presence and abundance, as well as habitat status over time, finding local expert knowledge useful for identifying some trends. Finally, Goffredo et al. [21] recruited recreational divers to gather data on marine species, as well as marine debris, finding that data reported was comparable in accuracy and consistency to that gathered by research divers. Increased reliance on SCUBA divers has enabled researchers to expand data collection efforts, while minimizing research costs.

Using participatory mapping methods, described below, local ecological knowledge can be used to provide an assessment of the relative quality and threat levels of coral reefs, as well as to understand which reefs are of most importance for human use activities. With this information, natural resource managers can more effectively direct management investments of value to the user community. By looking at the co-occurrence of reef quality characteristics and stress levels in coral reef areas used by people, resource managers can better decide whether to monitor reef quality, work to mitigate or reduce threats, initiate restoration activities, or simply divert management effort to other areas. In ideal cases, expert assessment would supplement biophysical data collected through regular coral reef monitoring activities. In other cases, where rich biophysical data does not exist, expert assessment may be the sole source of data to inform reef management.

1.1. Participatory mapping nomenclature

Participatory mapping is a general term that refers to a wide range of participatory and social research methods where spatial information is a core component. The terms public participation GIS (PPGIS), *participatory GIS* (PGIS), and *volunteered geographic information* (VGI) are common labels applied to spatial mapping processes involving different sampling groups. In the academic literature, there is continuing ambiguity over the use of the terms PPGIS/PGIS/VGI with PPGIS being the original term developed in 1996 at meetings of the National Center for Geographic Information and Analysis (NCGIA) to describe how GIS technology could support public participation for a variety of applications [33,34]. The term "participatory GIS" emerged from participatory approaches in rural areas of developing countries from the merging of Participatory Learning and Action (PLA) methods with geographic information technologies [37]. The term volunteered geographic information (VGI) was introduced by Goodchild [23] to describe the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals.

The concepts of "crowdsourcing" and "crowd wisdom" have become associated with VGI [40] and PPGIS [5] in recognition of the potential for a "crowd of people" to identity useful spatial information for a wide range of planning and management applications. The term "citizen science" has also become associated with VGI systems that involve research or monitoring activities conducted by amateur or non-professional scientists [24].

In this study, the recruitment of occupational SCUBA divers to map spatial information about reef conditions cannot be unambiguously situated within existing nomenclature. Is the mapping process best described as PPGIS, PGIS, VGI, crowd-sourcing, or citizen science? Are study participants volunteers, experts, or citizen scientists? The sampling and recruitment of study participants was purposive and not "volunteer" in the purest sense, the data collected was explicitly spatial, participants appear closer to "experts" than members of a "crowd"; and although some occupational SCUBA divers lack formal ecological training, they were requested to map reef conditions as a type of citizen scientist. For comparison, Goffredo et al. [21] and Lorenzo et al. [30] described recreational SCUBA divers in their studies as citizen "volunteers", Taylor et al. [41] described study participants as simply "long-term divers", while Forrester et al. [20] described divers engaged in reef monitoring activities as "volunteers" engaged in citizen science.

For convenience, the group of occupational SCUBA divers sampled and recruited for this study will be referred to as "experts" who engaged in *participatory mapping*; there is no compelling need to classify the mapping process as either PPGIS or VGI as it contains features common to both as described by Brown and Kyttä [7].

1.2. Reef assessment using expert participatory mapping

With coral reef ecosystems in decline globally, there is a pressing need to increase efforts geared toward their protection, restoration, and recovery [27]. Concurrently, there is a need to monitor the outcomes of such intervention by tracking and evaluating progress. However, because fiscal resources are increasingly limited, even basic scientific monitoring programs are unrealistic for some jurisdictions. For this reason, exploration of relatively low-cost monitoring options that can provide useful information on the current status as well as the long-term change of coral reef systems is needed. In this paper, the use of participatory mapping is demonstrated as one option for meeting this objective. Through mapping, social science researchers can harness the observational and experiential knowledge of SCUBA divers who are experts on the coral reefs where they dive.

In this study, an online mapping and survey tool to collect information on the status of coral reefs in the USVI from occupational SCUBA divers was developed. Our research was guided by the following