Colombian citizen science to improve coral reef conservation

Nohora H. Galvis, Rosa H. Galvis

Abstract The Foundation International Coral Reef Initiative (ICRI) Colombia through its Observatory for Coral Reefs and its National Network of Volunteer Observers of the Coral Reefs (RENOVO) have collaborated for 8 years under the following principles for conservation effectiveness: 1) Environmental Management is about people; 2) The knowledge of local users should be taken into account when decisions are made; 3) Monitoring is relevant for adaptive management. Scientific results are based on daily observations that were reported by artisanal fishermen and diving operators in a systematic way to monitor fishing and dive sites in Colombian coral reef areas. Qualitative reports, based on underwater videos and photos, served to study the progression of the invasion of Lionfish *Pterois volitans* in the Colombian Caribbean and to identify species in order to request governmental conservation in non-protected coral reef areas such Capurganá-Cabo Tiburon, Choco and Varadero, Cartagena. The quantitative data gathered as Catches per Effort Unit (CPEU) since 2009 also were useful to monitor changes in artisanal fisheries composition in Capurganá-Cabo Tiburon after the 2010 invasion of Indo-Pacific lionfish. The RENOVO´s citizen science successfully contributed to provide evidence that led the community that became the best guardian of the coral reefs, and prompted decision makers to improve conservation effectiveness, such as the new coral reef protected area of Capurganá-Cabo Tiburón.

Keywords: citizen science, coral reefs, conservation effectiveness, lionfish, management

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Introduction

Coral reefs globally are facing increasing disturbances even in uninhabited places. Smith et al. (2016) found a non-statistically significant difference between the coral cover average (CCA) at uninhabited islands (24%), and near inhabited areas (15%) in the Indo-Pacific

(which accounts for 75% of the world's reefs). Even at the isolated north of the Great Barrier Reef Marine Park, Australia, 35% mortality was reported after a recent massive coral bleaching event (T Hughes, pers. comm.). Climate change caused by human-induced carbon emissions is the major threat (Veron et al. 2009). However, Fenner (2012) considered that there is synergy between the effects of local pollution, direct and indirect destruction of coral reefs, overfishing and the effects of climate change on the degradation of coral reefs. Other hidden anthropogenic causes may only be identified when citizens report their observations of isolated coral reef areas. According to Galvis (1996, 1998a, 2001 and 2002), it is advisable to monitor indicators of Pressure, State, Impact and Management at each site to be able to clarify causes, effects and extent of threats in order to apply assertive conservation measures. Smith et al. (2016) also recommend measuring indicators of coral recruitment, reef growth, herbivory and benthos composition to understand trends. Since the ability to permanently monitor all the indicators in all areas is constrained by cost, it requires inter-institutional and expert multidisciplinary coordination with the involvement of the stakeholders. Besides the official monitoring performed by INVEMAR through its monitoring program SIMAC, Galvis (1989a, 2006), and Camargo et al. (2008) have evaluated and monitored the effectiveness of coral reef protection in Colombia with managers, scientists, divers and fishermen.

Methods

Stakeholder analyses (Bunce and Galvis 2002) were performed to identify the diving operators and artisanal fishermen from each coral reef. They were trained and engaged to send daily qualitative and quantitative reports through the Network of the users of the Coral Reefs (RENOVO, Observatory For Coral Reefs created by the Foundation ICRI Colombia since 2008) with detailed information (GPS location, depth, date and time) from the sites where they performed their commercial activities. Videos and photos served to monitor what is happening on the coral reefs. The visual records are scientific evidence when they are verified by the scientists in situ (geo-referenced). Qualitative data were collected to study the *Pterois volitans* invasion in the Colombian Caribbean Sea, based on 1244 reports sent through social media (Twitter @ArrecifesCoral @ICRIcolombia, Google-blog ICRI-Colombia and Facebook ICRI.Colombia), email, http://icri-

colombia.es.tl/EncuestaPezLeon.htm and iPhone. Stakeholder analyses were performed in each case study area. Quantitative reports from divers with their catches after derbies and Catches Per Effort Unit (CPEU) from fishermen in Capurganá were analyzed for possible *P. volitans* impact to the reef fisheries in this last Colombian invaded coral reef area. In situ verifications were performed in 2010, 2012, 2014 and 2016, as well as an Economic Valuation of the impact of dredging Varadero Reef.

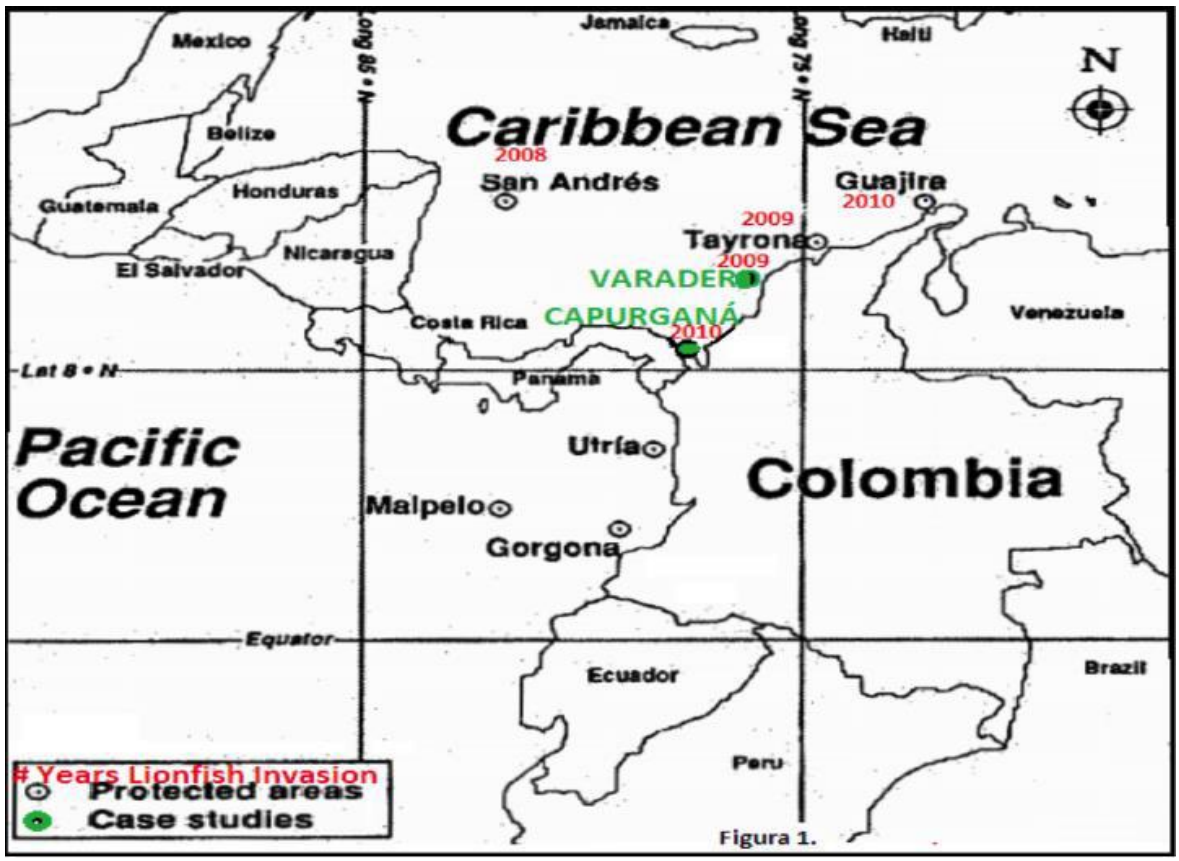

Fig. 1 Map of Colombian coral reefs

Results

The RENOVO´s reports came from all Colombian coral reef areas. Recent, newly reported areas updated the total areal coverage of Colombia's reefs to 4354 km². In the Pacific, these reef areas comprise only 15 km² (Gorgona, Malpelo, Utría, Nuqui and Punta Tebada). In the larger area, the Caribbean Sea, 2845 km² of reefs are at less than 50m depth and protected since the 1970's, while 1491.92 km2 of deeper corals have been protected since 2013. 77% of the Colombian Caribbean coral reefs are in the Seaflower Biosphere Reserve

(currently in dispute with Nicaragua) and 23% in: Tayrona, Guajira, San Bernardo, Corales Del Rosario, Punta Caribana, Varadero and Capurganá-CaboTiburón. The last three (which account for 3% of the corals) are not yet included in protected areas. The last two are the subject of case studies that were illustrated to the National Parks Authority and the Ministry of the Environment, recommending declaring them under protection, with supportive evidence sent by RENOVO´s reports containing videos and photos that identified in both case studies, indicators of healthy coral reefs as more than 50% healthy CCA. In contrast, in the protected areas there is 20% CCA. Regardless of the non-protection or protection framework, in all of them are similar impacts of turbidity, sedimentation, pollution, overfishing, and climate change. This condition has been worsening with the appearance of *P. volitans* (Linnaeus 1758), the invasive lionfish found in the Caribbean Sea. The progression of the invasion was confirmed by RENOVO as described in Figure 1, showing in red the years of appearance. A volunteer report was evidence that one lionfish, bought in Florida, USA, was imported and released in Barranquilla, Colombia (The first area invaded along the continental Caribbean coast). The owner of the lionfish (CEO of Telecommunications Enterprise, pers. comm.) had to move to Bogotá in mid-June, 2009 and could not afford the expensive maintenance of his pet far from the sea, so he released it in the wild. He thought that was the best option without knowing the potential impact. This does not contradict the scientific genetic findings but challenge the belief that *P. volitans* came to the Colombian Caribbean Sea only driven there from the North by the currents. The reported sizes of *P. volitans* confirm that at the beginning of the invasion the large invader specimens were ubiquitous, and now specimens > 400mm are at the reef slope and the fishing grounds to depths > 30m, and appear doubly numerous during night dives. Despite the invasion of *P. volitans*, the case study areas demonstrate signs of resilience to local and global threats that make a strong case for their urgent protection.

Varadero Case Study

The uniqueness of this biodiversity hotspot is its resilience despite pollution and sedimentation from a nearby industrial zone and the freshwater influence from the Dique Channel in the Cartagena Bay (Figure 2). The massive coral colonies show very few signs of morbidity and 10-20% mortality, with sizes > 3m2 , which represents 300 years or more of coral reef formation in 1.7 Km2, with indicators of healthy coral reefs such as parrot and

butterfly fishes (e.g., https://youtu.be/g32M7CNpBZo), sharks (e.g. *Ginglymostoma cirratum*; Bonnaterre 1788) and lobsters (*Panulirus Argus*; Latreille 1804; https://youtu.be/-lnI5EErSbQ). Varadero was first reported by fishermen from Bocachica and Barú in 1989 as a good artisanal fishing site (Galvis 1989b), later by diving operators as beautiful diving site, and finally by López et al. (2015) as worthy to provide world

Fig. 2 Map of options to enter Cartagena Bay. Varadero Case Study (Option 4)

knowledge about its resilience. The Colombian government has had plans in place since 1991 to dredge close by in order to enlarge a channel between Abanico and Draga Islands (Option 3), an alternative deeper channel to facilitate entrance of 150,000-tons ships that are entering only by the recently enlarged Bocachica Channel (Option 1). 1000 fishermen knowing the negative impact on their fisheries, protested in 2014 to avoid dredging by blocking the Bocachica entrance. Oil, transportation, and tourism companies, however, urge dredging. The recent enlargement of the Bocachica Channel caused 20% coral mortality to Varadero even though it is further from the coral reef. Therefore, it is expected a greater impact if dredging the options 3 or 4. After the petition of the Observatory in Pro

of Coral Reefs to the Colombian President, the Vice President inform to the media that the Ministry of Transportation hired the same MSc Biologist who allowed the Bocachica dredging for the EIA at a cost of $1,4 million USD before requesting the official environmental license to the Ministry of Environment to dredge. The RENOVOs reports were useful to inform both decision-makers and the community, providing support for arguments to protect the environment and helping to establish environmental valuation which, when factored in to total project cost, added $81 million US dollars to the $50 million US dollar cost for dredging, raising the combined social, environmental, and economic cost of the project to $131 million US dollars. In contrast, the option 2, Bocagrande seems to have a lower total cost of $60 million due to less environmental and social impact at the north end because it would avoid destruction of Varadero at the south end.

Capurganá-Cabo Tiburón, Case Study in Choco

Colombia-Panamá boundaries is in the process of being declared as a new coral reef protected area, after the recommendation of the Foundation ICRI Colombia which was based on the RENOVO´s reports that showed evidence of healthy coral cover at 70% (Fig. 3). Illustrations were sent to the environmental authorities justifying that turtles need to have healthy underwater ecosystems to be protected (e.g. https://youtu.be/IzN0FqOKKFg). Authorities confirmed interest to expand the area of the Sanctuary Playona that was only protecting the Acandí Beach for turtle nesting (J Miranda, Parks Director, pers. comm.). The stakeholder analysis and the identification of diving and fishing sites, contributed to build the baseline information for the formal community´s petition to the Colombian Government in order to declared it as Marine Protected Area (MPA).

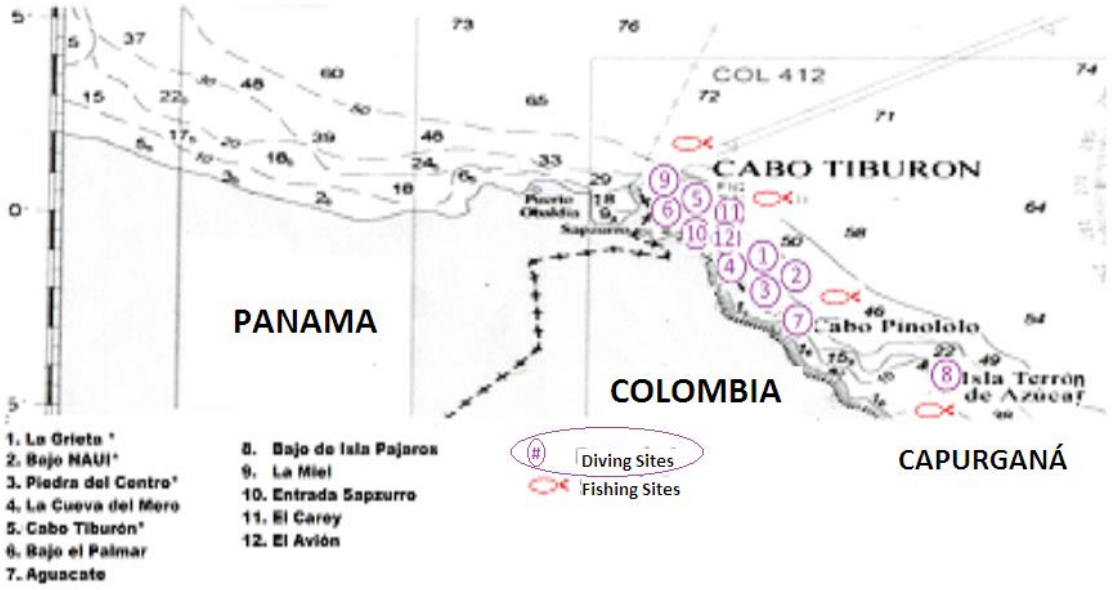

Fig. 3 Map of coral reefs in Capurganá, Colombia
#ÁreaMarinaProtegidaArrecifesCapurganáCaboTiburón

The fishing activity is also characterized from the daily CPUE, reported systematically by the president and accountant of the Association of Fishermen of Capurganá (PESCAPUR), and focused on productivity from line fishing of the family *Lutjanidae* or Snappers. The effort was described as constant during the progression of the lionfish invasion, in the same places with low variability (9+/- 3 Boats, 28+/-4 Fishermen) performing daily line fishing within twilight hours. Therefore, catches are an indicator of whether the reef fish are fished sustainably or not by line fishing. Loss of native fisheries productivity from *Lutjanidae* landings 2009-2013 was estimated at 30.67%. Figure 4, shows a slight increase in the composition in fishing for other fish families in the past two years: *Scombridae* (Tuna, Sierra and Bonitos), *Carangidae* (Yellowtail and Mackerels), and *Serranidae* (Groupers).

The number of native adult fishes on the reef slope increased substantially during the last years coexisting with *P. volitans*. In 2010, the Foundation ICRI Colombia promoted lionfish fishing, consumption, and the development of a local market with the support of the tourism sector, which perhaps was the successful strategy that made the difference.

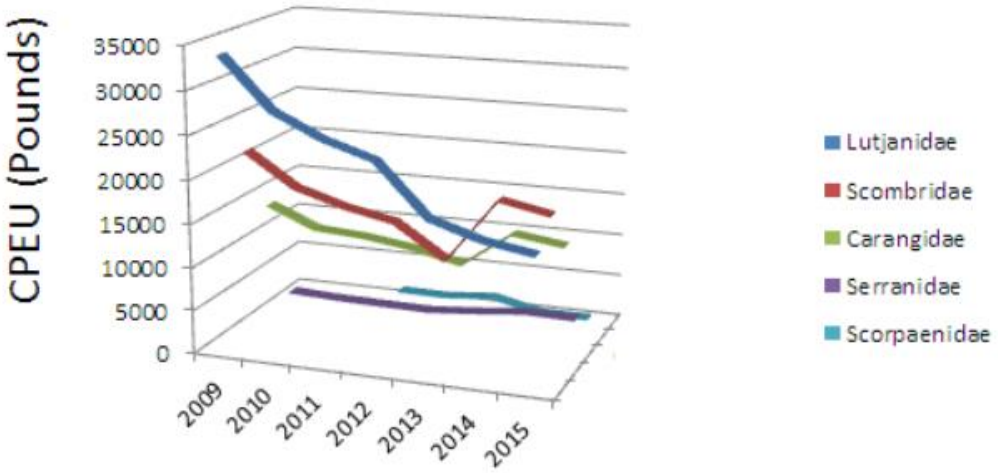

Fig. 4 Annual fishing catch reports in Capurganá, Colombia for five fish families, 2009 to 2015

As an economic alternative, the lionfish from S*corpaenidae* family entered the fishery in 2011, though catches have dropped in the last 3 years, after a peak of 2013. Comparison of catches reported by divers and fishermen showed that the hunters found fewer lionfish in the shallow areas, while line fishing >30m deep remains constant (Figure 5). This finding encourages line fishing (catches of 45cm long) as combined controlling strategy with Hawaiian hooks. The native fish community is being synergistically overfished and predated which may explain the combined negative effect due to the appearance of the new predator, despite that illegal fishing activities such as industrial trawling, dynamite and gillnets are less frequently performed in comparison with fishing reports before the appearance of lionfish. Other local threats such pollution and unsustainable development as well as climate change related global threats may also affect the reef fisheries.

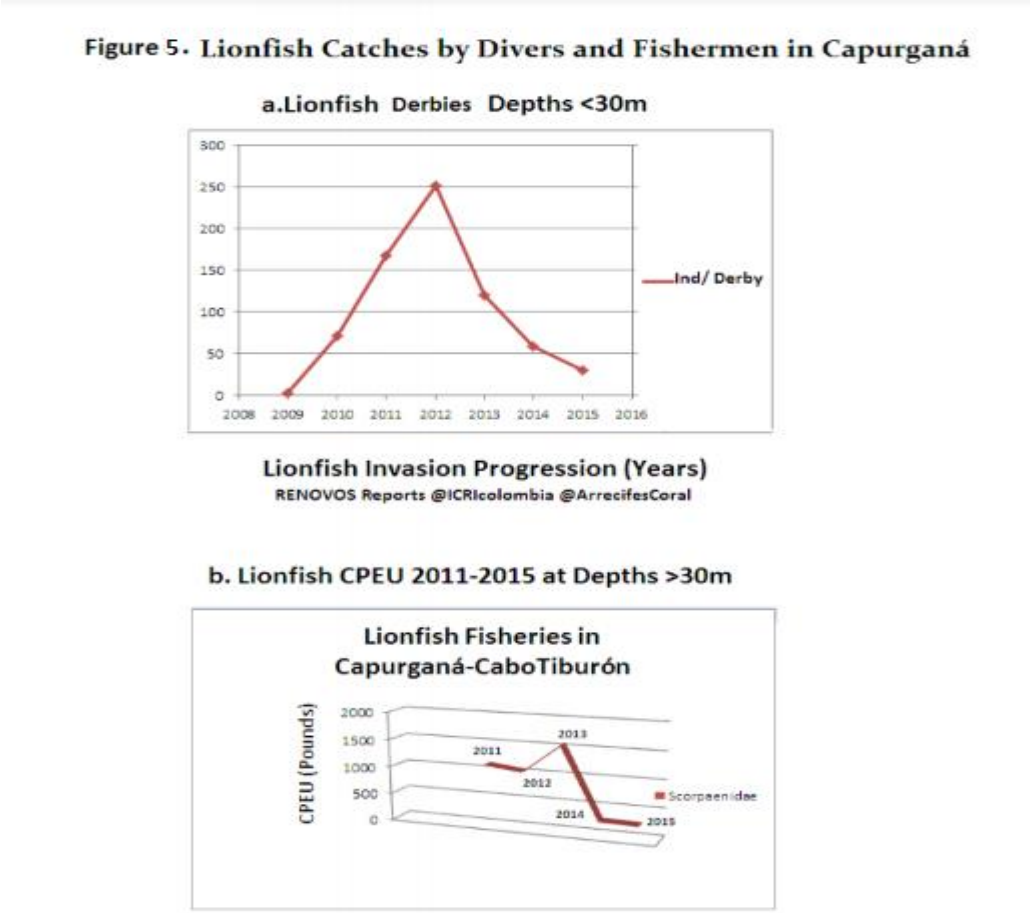

Fig. 5 Lionfish catches by divers and fishers in Capurganá, Colombia, (a) above 30 m depth between 2009 and 2015, and (b) below 30 m depth from 2011 to 2015

Discussion

Larger spatial and temporal series of data are required to reduce the uncertainty about conservation effectiveness. If only scientists are involved, the cost of research can be excessive. Cohn (2008) discussed how collaborations between scientists and volunteers have the potential to broaden the scope of research and enhance the ability to collect scientific data by engaging interested members of the public to contribute valuable information as they learn about wildlife conservation in their local communities. Citizen science offers a potentially cost-effective way for researchers to obtain large data sets over large spatial scales (Fairclough et al. 2014).

Recreational fishers have contributed voluntarily, at an international level to scientific data collection via catch and effort logbooks and surveys, and both contributory and collegial fish-tagging studies, (e.g. http://info-fish.net/westag, and with iPhone http://thefisheriesblog.com/2013/02/04/citizen-science-fishing-for-data/). Eddy, Pande, and Gardner (2014) recommended a multi-year survey of an ecosystem prior to establishing a protection framework, providing a baseline against which to measure any future changes. RENOVO is proving to be useful by involving divers and fishermen, while helping scientists to monitor, on a daily basis the potential changes in ecosystem health. The stakeholders of the reef report their commercial activities and perceptions, which is very valuable information for managers. The study of the invasive lionfish progression was the first test of the RENOVO operationally. It was more successful than the INVEMAR´s official citizen science webpage (http://cinto.invemar.org.co/invasoresmarinos/), perhaps due to the RENOVO´s personal communication and flexible ways to report the systematically collected data. It confirmed what Whitfield et al. (2002) pointed out, that accidental or intentional release is frequent for this species. Also, Freshwater et al. (2009) predicted that the Panama-Colombia gyre was the last location for dispersal of lionfish, as it is the most isolated region within the Caribbean. Based on the reports, the authors recommended how to improve the lionfish control to the fisheries and environmental authorities to coordinate the environmental education to fishermen and enforcement (#ReglamentaciónPesqueraPezLeón) to avoid overfishing with scuba that may increase fishing pressure on the lobster fishery and the hydrobiological resources such as parrot fishes and other fishes of the reef. Other direct recommendations were addressed to the Colombian Authorities to improve conservation effectiveness and include the two case studies under IUCN categories of protection. Current coral reef protected areas show low performance in the social and governance indicators. Low-income levels and few opportunities for communities living close to coral reefs, low governability, weak communication among stakeholders and with authorities, reflected low adaptive capacity of communities to comply with restrictive conservation rules, showing that establishment of a protected area is necessary, but that currently there is an insufficient condition to guarantee conservation goals (Camargo et al. 2008). Global warming is increasing the frequency and severity of coral bleaching, which is causing morbidity and mortality affecting coral reefs.

Healthy reefs can show rapid recovery of microalgae that live symbiotically in the colonies of resilient coral reefs.

More economic valuations should serve to convince top decision makers with monetary priorities that it is a better investment to effectively protect the coral reef areas of Colombia as well as to avoid plans for the destruction of coral reefs, due to the high cost of ecosystem restoration, and the high environmental and social impacts. The EIAs should consider the cost of restoring coral reefs, as it is estimated at $ 270,000 km2 per year (Burke et al. 2002). For the Varadero Coral Reef, considering that the real restoration will take >300 years, its destruction and potential restoration will cost $131 million dollars by applying economic valuation (Galvis 1998b, 1999 and 2002) estimating the local loss of annual economic net benefit of healthy coral reef areas for tourism and fisheries. The environmental cost would increase by global loss of a resilient coral reef ecosystem.

In the Colombian Caribbean, there are signs of general biological and ecological overfishing. This is the result of an open access fishery. It is possible, based on the results inferring about the condition of the population as set by Fenner (2012), stress variation may be assessed when data is taken before and after the effect study (appearance of lionfish) as a baseline. Native piscivore populations are already severely reduced across a majority of the Caribbean due to overfishing; relatively healthy populations still exist in remote locations with low human populations and inside some marine reserves (Stallings 2009). McManus et al. (1992) referred to states of overfishing related to the effect on the community, as people can act as predators and/or as removers of predators to cause a variety of possible changes. According to the graphical distribution of the case study, multi-species fishery showed a Tilt-on pattern since humans are switching predators, becoming fishers of lionfishes. The Tilt-on effect causes an increase in evenness and freeing niche-space for other species, conceivably leading to an increase in species richness, simple diversity, Shannon-Wiener diversity, and of course, evenness (McManus et al. 1992). Therefore, there is a hope that evidences the native commercial species may recover, after almost two decades of the reduction in industrial fishing pressure. Hence, the relevance of the declaration of a scheme of coral reefs ecosystems to facilitate stock recovery and to keep control on the lionfish invasive population as an economic alternative for the artisanal

fishermen. Management recommendations for the Tilt-on pattern include a design for a proposed marine reserve/park, providing alternative forms of living, employment, ecotourism, and slowing down population (McManus et al. 1992). The length of the recovery at the case study seems to be within the 20-year process. According to Eddy, Pande, and Gardner (2014) exploited reef fishes may recover from reduction of fishing pressure ongoing after 20 years, individual highly targeted species may exhibit profound positive changes in abundance, size, and biomass. The change in fisheries productivity may be estimated with the prices of the fishing products sold, as it is a method for economic valuation (Galvis 1998b, 1999 and 2002).

The process of declaring the Capurganá-CaboTiburón MPA should be accelerated considering that the Information System on Marine Biodiversity (SIBM) Component already shows healthier coral reefs than protected areas such as Corales del Rosario. Involvement of communities in strategic ecosystems management appears to be a requisite to improve effectiveness of protected areas, and participatory strategies, such as co-management, offer opportunities to improve governability. The involvement of the community within this citizen science scheme makes them aware that they are part of the coral reef area management and their activities are relevant to improve the conservation objectives which provide benefits for their enterprises such as learning about the trends of their fishery, bridging stakeholder communication with decision-makers, understanding the progression of the #Lionfish invasion and other problems, evaluating and monitoring the state of health, improving conservation effectiveness and Identifying new coral reef species in new places to be protected such as #CoralesBahíaCartagena #Varadero #ÁreaMarinaProtegidaArrecifesCapurganáCaboTiburón

References

Best B, Pomeroy R, Balboa C (eds) (2000) The hows and whys of socioeconomic aAssessments. Implications for coral reef management and policy. Relevant findings from the 9th International Coral Reefs Symposium, Bali, Indonesia http://pdf.usaid.gov/pdf_docs/Pnada629.pdf

Burke L, Selig E, Spalding M (2002) Reefs at risk in Southeast Asia. Washington, DC: World Resources Institute. ISBN: 1-56973-490-9. 72 p

Camargo C, Maldonado JH, Alvarado E, Moreno-Sánchez R, Mendoza S, Manrique N, Mogollón A, Osorio JD, Grajales A, Sánchez JA (2008) Community involvement in management for maintaining coral reef resilience and biodiversity in southern Caribbean marine protected areas. Biodiversity and Conservation 18: 935-956

Cohn JP (2008) Citizen science: can volunteers do real research? Bioscience 58: 192–197

Eddy TD, Pande A, Gardner J (2014) Massive differential site-specific and species-specific responses of temperate reef fishes to marine reserve protection Global Ecology and Conservation 1: 13–26

Fairclough DV, Brown JI, Carlish BJ, Crisafulli BM, Keay IS (2014) Breathing life into fisheries stock assessments with citizen science. Scientific Reports 4, Article 7249 http://dx.doi.org/10.1038/srep07249

Fenner D (2012) Review: Challenges for managing fisheries on diverse coral reefs. Diversity 4: 105-160

Freshwater DW, Hines A, Parham S, Wilbur A, Sabaoun M, Woodhead J, Akins L, Purdy B, Whitfield PE, Paris CB (2009) Mitochondrial control region sequence analyses indicate dispersal from the US East Coast as the source of the invasive Indo-Pacific lionfish *Pterois volitans* in the Bahamas. Marine Biology. https:// dx.doi.org/10.1007/s00227-009-1163

Galvis NH (1989a). Evaluación cuantitativa de las Llanuras Arrecifales de Pavitos, Parque Nacional Natural Corales Del Rosario, Cartagena, Col. Boletín Ecotrópica, Museo del Mar, Universidad Jorge Tadeo Lozano. 19:27-54

Galvis NH (1989b) Análisis socio-económico de las comunidades pesqueras de la Boquilla, Tierra Bomba, Barú y Ararca. Revista Recursos Hidrobiológicos, Inderena 2: 70-84

Galvis NH (1996) Monitoreo de arrecifes coralinos en Colombia. En: Colombia revista Geotrópica. ISSN: 0122-8579 U. J. T. L. del Área de los Recursos Naturales, Octubre 10: 14 – 21

Galvis NH (1998a) Creación de la contabilidad ambiental de los arrecifes coralinos como instrumento de manejo. Memorias del Seminario Nacional de Política, Ciencias y Tecnologías del Mar, October 26-30. CD-Rom CCO-COLCIENCIAS

Galvis NH (1998b) Importancia de la valoración económica de los arrecifes coralinos en Colombia. Boletín Pólipos, Sociedad Colombiana para el estudio y conservación de los arrecifes coralinos, SCCAR

Galvis NH (1999) Valoración económica de los arrecifes coralinos en Colombia. Revista Geotrópica. Área Recursos Naturales, Universidad Jorge Tadeo Lozano ISSN: 0122-8579

Galvis NH (2001) Monitoring ecological and socioeconomic indicators for management of coral reefs in Colombia. Proceedings of the International Conference on Scientific Aspects of Coral Reef Assessment, Monitoring, and Restoration. Bull Mar Sci 69: 847–859 http://www.ingentaconnect.com/content/umrsmas/bullmar/2001/00000069/00000002/art00047

Galvis NH (2002) Análisis de multicriterios para la concertación, formulación, gerencia, seguimiento y monitoreo de proyectos ambiéntales complejos." Colombian Book Ed: Javergrafics 150 p

Galvis NH (2006) Implementing collaborative decision-making in Latin America to improve coral reef management. File Oral Presentation # 084 at the First International Marine Protected Areas Congress, Geelong, Australia Proceedings: 370-371

López-Victoria M, Rodríguez-Moreno M, Zapata FA (2015) A paradoxical reef from Varadero, Cartagena Bay, Colombia. Coral Reefs 34: http://dx.doi.org/10.1007/s00338-014-1246-y

McManus JW, Nafiola Jr CL, Reyes Jr RB, Kesner KN (1992) Resource ecology of the Bolinao coral reef system. ICLARM Stud Rev 22, 117 p

Smith JE, Brainard R, Carter A, Grillo S, Edwards C, Harris J, Lewis L, Obura D, Rohwer F, Sala E, Vroom PS, Sandin S (2016) Re-evaluating the health of coral reef communities: baselines and evidence for human impacts across the central Pacific. Proc. R. Soc. B 283: 20151985. http://dx.doi.org/10.1098/rspb.2015.1985

Stallings CD (2009) Fishery-independent data reveal negative effect of human population density on Caribbean predatory fish communities. PLoS One 4, e5333

Veron JEN, Hoegh-Guldberg O, Lenton TM, Lough JM, Obura DO, Pearce-Kelly P, Sheppard CRC, Spalding M, Stafford-Smith MG, Rogers AD (2009) The coral reef crisis, the critical importance of <350 ppm CO2. Mar Pollut Bull 58: 1428–1436

Whitfield P, Gardner T, Vives SP, Gilligan MR, Courtenay WR Jr., Ray GC, Harem JA (2002) Biological invasion of the Indo-Pacific lionfish (*Pterois volitans*) along the Atlantic Coast of North America. Mar Ecol Prog Ser 235: 289-297