Marine Conservation Outcomes Are More Likely When Fishers Participate as Citizen Scientists: Case Studies from the Mexican Mesoamerican Reef

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Abstract
Small-scale fishers on Caribbean coral reefs have exploited fish spawning aggregations (FSAs) for generations, but intense fishing has led to the loss of traditional aggregation sites. In many areas, the traditional ecological knowledge (TEK) of fishers has contributed greatly to the characterization of spawning aggregations and implementation of local conservation initiatives. TEK has identified more than 40 potential FSA sites along the coast of the Mexican Mesoamerican Reef. These sites have been characterised and scientifically validated, in some cases with traditional western science and in others, with a participatory citizen-science approach. The objective of this work is to compare the science and conservation outcomes at these FSA sites. We report that those FSA sites where scientific surveys were conducted without community participation remain unprotected. By contrast, the FSAs where local fishers were engaged in characterization and subsequent monitoring, are now protected at the behest of the fishers themselves. Conservation initiatives to protect FSAs can be more effective through a combination of TEK, western science, and participatory citizen science involving local fishers.

Keywords
Spawning Aggregation, Traditional Ecological Knowledge, Fishers, Citizen Science

Introduction

In the past decade, scientific surveys involving the participation of members of the public (citizen science) have greatly increased in number (Conrad & Hindley 2011, Theobald et al. 2015). Bonney et al. (2014) define citizen science as scientific research and monitoring conducted by non-specialist individuals who are involved in collecting, categorizing, transcribing, or analysing scientific data. Citizen science encompasses a broad range of subjects and methods, covering topics ranging from observational data collected by keen hobbyists (e.g. bird surveys, Butcher & Niven 2007), to volunteer computing in which citizens do not actively participate, but lend resources, for example processing power (e.g. pulsar image analysis, Knispel et al. 2010). Objectives can be research-based to answer specific scientific questions, or focus on community-based monitoring (CBM), including population assessments, impact assessments and adaptive management (Conrad & Hilchey 2011).

Technological advances driven by the smartphone revolution have allowed multitudes of people to participate in citizen science projects, particularly in terrestrial environments. Wider participation of citizen scientists reporting sightings of key species has increased the size, geographical distribution and thus the analytical power of the datasets used to address complex large-scale issues (e.g. Butcher & Niven 2007, McClellan et al. 2014, Theobald et al. 2015). Specific conservation outcomes are also targeted by CBM whereby citizen scientists can provide and enhance the sustainability of long-term data collection and address specific management needs (Cigliano et al. 2015).

The marine environment poses challenges that may limit citizen scientists' involvement. Marine initiatives are proportionally underrepresented (Roy et al. 2012, Theobald et al. 2015) likely due to the difficulty and expense of project implementation. Limiting factors can include the cost of the equipment required, boat hire, safety and liability issues or even unclear access and resource rights (Roy et al. 2012, Cigliano et al. 2015). Due to these limitations, marine citizen science is more common in high-income countries or popular SCUBA diving destinations (Pattengill-Semmens & Semmens 2003, Goffredo, Piccinetti & Zaccanti 2004, Ward-Paige et al. 2010). Coastal marine users and stakeholders in developing countries do provide information to scientists, but information transfer has more commonly drawn on their traditional ecological knowledge (TEK) rather than active participation in data collection (Schafer & Reis 2008, Valdés-Pizzini, García-Quijano & Schärer-Umpierre 2012, Butler et al. 2012, see Thornton & Maciejewski-Scheer 2012 for review).

Fish spawning aggregations (FSAs) are large gatherings of fish for the purpose of reproduction (Sadovy de Mitcheson & Colin 2012). On coral reefs, FSAs occur at specific locations and times of year (Heyman & Kjerfve 2008, Gleason, Kellison & Reid 2011, Colin 2012, Kobara et al. 2013), and in most cases, local fishers were first to discover such sites. FSA sites can be multispecific with different fish species using the same area at different times of the year (e.g. Heyman & Kjerfve 2008). In the Caribbean Sea, commercially important fish, such as groupers (Epinephelidae) and snappers (Lutjanidae) form aggregations to spawn (Sadovy de Mitcheson et al. 2008). Fishers can harvest large numbers of fish with minimal effort at FSA sites during spawning seasons. In many cases, fishing has led to local extirpation of the FSA (Sadovy & Domeier 2005, Sadovy de Mitcheson et al. 2008, Sadovy de Mitcheson et al. 2012).

Worldwide, conventional fisheries management has relied on traditional tools such as size and catch limits, gear restrictions, and closed seasons. In many developing countries, however, such tools are difficult to implement given limited resources for effective enforcement. Small, completely protected marine reserves have been cited as effective tools for protecting FSA sites (Erisman et al. 2015). However, knowledge gaps in the understanding of the location of FSAs exist (Kobara et al. 2013) and, as such, managers can be reluctant to implement conservation measures. A review of the objectives for 55 Caribbean multiuse protected areas (PAs) found that only four considered FSA management in their design (Appeldoorn & Lindeman 2003). In one extreme example, a Black Grouper FSA was discovered just beyond the boundary of a PA (Eklund, McCellan & Harper 2000) and therefore offered no protection.

In his thought-provoking and somewhat provocative paper, "The case for data-less management" Johannes (1998) explained how conventional biological training has created conditions in which scientists can be reluctant to commit to conservation management decisions without a quantitative description of the resources at hand. However, due to the data gaps still present in FSA science, and the continued population declines in many fish species that aggregate to spawn (Sala, Ballesteros & Starr 2001, Sadovy & Domeier 2005, Sadovy de Mitcheson et al. 2012) data-poor management approaches are now being considered. Data-poor management however, does not necessarily mean data-free (as proposed by Johannes 1998), and advocates of the approach draw on all available data to propose optimal management solutions that account for both the existing scientific information and the TEK of the local fishers (Heyman 2011).

In this study, we define traditional western science (*WS*) as research conducted by trained scientists (from academia or NGOs) that is objective, generally quantitative, analytical, and reductionist, and often results in publications and in some cases, policy and management recommendations. In contrast, participatory citizen science (*CS*) uses a western science approach, but in addition, involves the continued participation of fishers in the scientific aspects of research, analysis, and in making and implementing policy recommendations.

Both traditional western science and participatory citizen science approaches have been used to verify and characterize FSA sites along the Mexican portion of the Mesoamerican Reef (MAR) but no comparisons between these techniques and their respective conservation outcomes have been made previously. All potential FSA sites were originally identified via TEK. Of these sites, some were characterized using solely traditional western science and conducted by scientists from either academia or from NGOs. Others were characterized using a participatory citizen science approach involving local fishers as citizen scientists with support from researchers and NGOs and has proven effective (Heyman 2011, Hamilton et al. 2012, Heyman et al. 2014, Fulton et al. in press). The objective of this paper is to compare the scientific and conservation outcomes achieved by these differing approaches.

Methodology

Study Area

The MAR extends over 1,000 km from the tip of the Yucatan Peninsula in Mexico to the Bay Islands of Honduras. The study area covers approximately 230 km from the northern edge of the Sian Ka'an Biosphere Reserve to Xcalak on the Belize border (Figure 1). This central and southern section of the State of Quintana Roo lacks the mass tourism destinations found in the north of the state and is home to three Protected Areas (PA); the Sian Ka'an Biosphere Reserve complex (SKBR), Banco Chinchorro Biosphere Reserve (BCBR) and Xcalak Reef National Park (XRNP). All PAs are zoned as multiuse with fishing permitted in most of the area, but with restrictions, particularly on gear type. The area known as "Costa Maya" is not protected and tourism development is underway.

Fishing activities occur throughout the study area with seven fishing cooperatives totalling approximately 209 fishers principally catching lobster and small amounts of finfish. An eighth cooperative (eight fishers) exclusively targets fin-fin. There are an approximately 15 additional individual permit holders and an unknown number of unregulated fishers that operate in the area.

Figure 1. Map of the study area

Review of FSA Scientific Knowledge in the Mexican MAR

TEK provides the foundation for all FSA work in the Mexican MAR. The first study to document several FSAs was completed by Aguilar-Perera (1994). Sosa-Cordero et al. (2002) published the most comprehensive study to date. In both cases, the principal data source was interviews and surveys with veteran fishers, completed by documented sources and grey literature. Sosa-Cordero et al. (2002) identified 39 potential FSA sites for diverse species. Local NGOs replicated the studies on a smaller scale during the mid-2000's (Franquesa-Rinos & Loreto-Viruel 2006, ASK & COBI 2010). The NGOs worked closely with the fishers to reconfirm and prioritise the Sosa-Cordero et al. (2002) data. The 39 original FSAs were revised down to 29 as some sites were clustered and likely represented the same FSA (Fulton et al. 2016).

The synopsis of site characterization was divided by the approach of the group who conducted the work. We searched published literature available in online scientific databases and in grey literature to map the fieldwork conducted. Three groups were identified: Academics using western science without fisher involvement (western science "*WS*"), NGOs using western science without local fishers ("*WS**"), and Citizen Science (western science involving local fishers "*CS*"). For each study, we identified the methodology used, if bathymetric maps were created, if FSAs were validated and by what method, and the level of involvement of local fishers.

Results

Methodologies for FSA Site Characterization

The technical methodology followed by each group (*WS*, *WS** and *CS*) was similar (Table 1). Each group mapped the spawning sites (sketch maps and/or bathymetry) and conducted underwater visual censuses (UVC) to document spawning behaviour (*WS*: Aguilar-Perera 1994, Medina-Quej et al. 2004. *WS**: ASK & COBI 2010. *CS*: Franquesa-Rinos & Loreto-Viruel 2006, ASK & COBI 2010, Fulton et al. 2016). In one site, the group did not conduct in-water verification, relying instead on fishery-dependent data to identify the FSA (*WS*: Castro-Pérez, Acosta-González & Arias-González 2011).

Characterization of FSA sites using participatory citizen science (CS)

The San Juan FSA, in the northern part of the SKBR, was characterized by a local NGO and trained fishers from the community in 2005 (Franquesa-Rinos & Loreto-Viruel 2006) and 2008 (ASK & COBI 2010) (Figure 2; Table 1). The site was mapped and biologically characterized through underwater visual census (UVC). Divers reported purported spawning aggregations of 200 Nassau Grouper and 100 Black Grouper (*Mycteroperca bonaci*), from changes in colouration and behaviour, located on the shelf-edge in 35 m of water. Fishers from the same community returned in 2015 with other scientists and reported 50 Nassau grouper and 30 Black Grouper (Fulton et al. 2016). Due to the observed decline in fish abundance in these aggregations, recommendations were made to the community to close the site to fishing.

The Punta Allen FSA, also in northern SKBR followed a similar process to San Juan. NGO and community characterizations in 2005, 2008 and 2015 (Franquesa-Rinos & Loreto-Viruel 2006, ASK & COBI 2010, Fulton et al. 2016) reported 1,000 Nassau Grouper located at 35 m depth on a large spur and groove coral reef (Figure 2, Table 1). The fishers reported that the site has been rarely fished in the last 10 years, but with the observed abundance of this endangered species in a spawning aggregation, it was considered worthy of legal protection.

The Punta Herrero site, located in the southern part of the SKBR, was characterized through *CS* with fishers from the fishing cooperative "José María Azcorra", beginning in 2008 (Table 1; Figure 2). A small FSA of Nassau Grouper was reported at a depth of 30 m, on small drop-off in an area of strong currents (ASK & COBI 2010). Site protection was proposed in 2010 to protect the Nassau Grouper FSA. Between 2013 and 2015, fishers and scientists mapped and further characterized the site with UVC and reported FSAs of 150 Nassau Grouper, 30 Yellowfin Grouper (*Mycteroperca venenosa*), 1,500 Mutton Snapper (*Lutjanus analis*), and 800 Dog Snapper (*Lutjanus jocu*) (Fulton et al. 2016).

Table 1. Current status of verified fish spawning aggregation sites in central and southern Quintana Roo.

Characterization of FSA sites using western science (WS/WS)*

For over 100 years, fishers had been aware of a Nassau Grouper FSA at Mahahual (Aguilar-Perera 1994) (Figure 2). The site was initially described and mapped between 1988 and 1990 by *WS* (Aguilar-Perera 1994) and used UVC to document 1,000 Nassau Grouper on a shallow reef between 10 and 16 m depth. Aguilar-Perera (1994, 2013; Table 1) was the first to make management recommendations for aggregation sites in the Mexican MAR, with the particular aim of preventing the disappearance of the Nassau Grouper FSA at Mahahual. These recommendations included banning spearguns, implementing a closed season, and improving surveillance and enforcement. The study also recommended working with the fishers to highlight the ecological importance of the FSA in Mahahual and provide economic alternatives to reduce fishing pressure on the aggregation. Efforts to verify the presence of FSAs at the site in 2016 confirmed that Nassau Grouper no longer aggregate there.

The Maya-Ha (Black Grouper FSA site, located in the Costa Maya region, was originally verified by a local NGO in 2009 (*WS**) without local fisher participation (ASK & COBI 2010) (Figure 2; Table 1). Site-specific management recommendations were not made. The site was revisited in 2016 with fishers who were not local to the area. The team produced a bathymetric map of the site and used UVC to document aggregations of 30 Black Grouper and 45 Cubera Snapper (Fulton et al. 2016).

In Xcalak, commercial catch of Nassau Grouper was measured and UVC conducted by *WS* on the FSA between 2001 and 2002 (Medina-Quej et al. 2004). The FSA of 3,000 groupers, the largest reported in the literature in Mexico, forms on a spur and groove reef at approximately 35 m depth (Figure 2; Table 1). The researchers report that fishing pressure was low and recommended that the management plan for the PA take in to consideration the FSA site.

Researchers (*WS*) published the first record of a Mutton Snapper FSA in Banco Chinchorro (Castro-Pérez, Acosta-González & Arias-González 2011). Coordinates were provided for the FSA based on catch data provided by the fishers; however, the FSA was not visually verified. The authors mentioned that fishing impact in Banco Chinchorro is low to moderate due to the restrictions of the biosphere reserve, and recommended seasonal closures for the FSA. A community fisher *CS* monitoring team was established in 2012 in collaboration with NGOs and the reserve authorities. The team visually confirmed an aggregation of 3,000 Mutton Snapper at a location 3 km from the shallow banks where the aggregation was first reported at a depth of over 40 m on the shelf edge (Figure 2; Table 1; Heyman et al. 2014).

Protection Status

Mexican legislation includes several instruments that can be used to protected critical habitat, ecosystems or species. The two instruments relevant for this article and implemented in the Mexican MAR are multiple-use Protected Areas (PA) managed by the National Commission of Natural Protected Areas (CONANP in Spanish) and no-take zone (NTZ) Fish Refuges managed by the National Commission of Aquaculture and Fisheries (CONAPESCA). PAs include different zoning schemes that can limit and prohibit fishing, such as core zones. Fish Refuges are a relatively new instrument, created under the Sustainable Fisheries and Aquaculture Law in 2007 (Secretaria de Gobernación 2007) and first implemented in 2012.

Protection status of FSA sites characterized using participatory citizen science (CS)

The three northernmost FSA sites (San Juan, Punta Allen and Punta Herrero) are located in the SKBR. The Federal PA was established in 1986 (Secretaria de Gobernación 1986) and contains a multiple-use zoning scheme of which 100 km^2 are closed to fishing, except for subsistence and lobster fishing (Figure 2). The management plan for the PA states that grouper and snapper FSA are found inside the PA no-take zones (Secretaría de Medio Ambiente y Recursos Naturales 2014); however, the three confirmed FSA were verified 20 years after the PA was created and efforts to locate FSA in the PA no-take zones have not been successful. The characterized San Juan FSA described in the study is located 2.8 km from one such no-take zone, the Punta Allen FSA 6 km distant, and the Punta Herrero FSA 4.4 km away. Effort control also exists as spearguns and nets are prohibited throughout the PA.

In 2013, the Punta Herrero FSA was protected under the fisheries legislation at the petition of the local fishers with help from local NGOs (Secretaria de Gobernación 2013). The Punta Herrero Fish Refuge covers 4.28 km^2 and represents the first time that this legislation was used to protect a FSA in Mexico. In 2016, the San Juan and Punta Allen sites were also protected at the petition of the fishing community using the same legislation (Secretaria de Gobernación 2016) with 16.28 km^2 and 15.82 km^2 Fish Refuge respectively.

Protection of FSA sites characterized using western science (WS/WS)*
The Mahahual and Maya-Ha FSAs are not found within a PA. The Mahahual FSA was reported as extinct by 1996 (Aguilar-Perera 2006, 2013). Considerable *WS* research was conducted on the site (Aguilar-Perera 1994, 2006, 2013, Aguilar-Perera & Aguilar-Davila 1996) and it remains the best-described FSA to date in Mexico despite no continuous monitoring program being implemented. Management recommendations were implemented as the FSA disappeared with CONAPESCA enacting a ban on spearguns and gill nets in 2006 and a complete ban on fishing during spawning season in 2007 (Aguilar-Perera 2013). Lack of enforcement saw these actions abandoned the following year. The Maya-Ha FSA is believed to be fished from fishers from the town of Mahahual, but no data exists on effort and landings and no efforts have been made to manage or protect the FSA.

In Xcalak, the FSA is located within the XRNP, a PA created in 2000 (CONANP 2004). The PA contains a specific “Special Production Zone - Grouper” (*Zona de Aprovechamiento Especial Mero*) in which the management plan recognises the presence of a FSA (although commercial fishing is permitted). This site, known as Punta Gavilan, was identified from TEK over 20 years ago (Aguilar-Perera 1994) but no data have since been published to confirm the presence of spawning fish. The visually verified aggregation (Medina-Quej et al. 2004) lies 1.9 km to the south of the Special Production Zone and is therefore not protected from fishing, although pressure is reportedly low (CONANP personal communication). The site continues to be monitored by a local research institute (*WS*) and appears healthy despite some annual fluctuations in Nassau Grouper abundance (Alejandro Medina-Quej, personal communication).

The Banco Chinchorro FSA is found with the BCBR, a Federal PA that includes 68 km^2 of no-take zones. Effort controls also exist; spearguns are prohibited by the management plan during fish reproduction seasons (SEMARNAP 2000). Catch data is collected during the spawning season by the reserve authorities. The recently documented Mutton Snapper FSA is located approximately 800 m outside the edge of the nearest NTZ (Table 1, Figure 2).

Figure 2. Location of documented FSA in the Mexican MAR.

Discussion

Conservation Outcomes of WS, WS and CS-led FSA Studies*
This study compared the outcomes from case studies using western science (*WS*) to those using a participatory citizen science (*CS*) approach for the characterization and conservation of fish spawning aggregation sites in the Mexican MAR. All potential spawning sites were first identified with fishers’ traditional ecological knowledge. Our results show that the four FSA sites characterized by researchers using western science without community involvement (Mahahual, Maya Ha, Xcalak, and Banco Chinchorro) remain open to fishing. In each of these cases, *WS* provided site characterizations and clear management recommendations (Aguilar-Perera 1994, Medina-Quej et al. 2004, ASK & COBI 2010, Castro-Pérez, Acosta-González & Arias-González 2011). None of the recommendations have been implemented effectively. One site serves as an extreme example: the FSA site at Mahahual was fished to extinction (Aguilar-Perera 2013). By contrast, the three FSA sites where the fishing community took part in the FSA characterization, monitoring, and evaluation, (San Juan, Punta Allen, Punta Herrero) are now protected within no-take zones after fishers petitioned the government for their establishment (Secretaria de Gobernación 2013, 2016; Table 1).

The successful implementation of fisheries conservation measures presented in this paper occurred when western science, citizen science and traditional ecological knowledge were effectively combined. When one of the three components was lacking, conservation goals were not achieved. The protection of three FSAs documented herein was made possible through community level collaborations between researchers, civil society and fishers. A citizen science programme resulted in the training of 38 local fishers as SCUBA divers who characterized the FSA sites near their communities and generated the data required for their protection using the existing legal framework. The sites were protected by the National Commission of Aquaculture and Fisheries (CONAPESCA) under the fisheries legislation, a flexible and dynamic management tool. These areas were, and continue to be, considered both data-poor and with low enforcement by authorities, although fishers operate community surveillance programmes with some governmental support.

In contrast, at the four FSAs where a *CS* component was not included (Table 1), information and management recommendations were generated (Aguilar-Perera 1994, 2006, Medina-Quej et al. 2004, Castro-Pérez, Acosta-González & Arias-González 2011), but not implemented with long-term success. For example, CONAPESCA temporarily implemented some of the recommendations made for the Mahahual FSA, however, they were only briefly enforced and the aggregation ceased to form shortly after (Aguilar-Perera 2006, Aguilar-Perera 2013). Incidentally, this FSA had been fished at low levels for decades, but a race to fish in recent years, including the use of new fishing gear, harpoons and, reportedly, dynamite (Aguilar-Perera 1994) quickly led to its extinction.

Driving factors for FSA protection

Social and economic factors need to be recognised as important contributions to the enabling environment for the establishment of the three NTZs in this study. The cooperatives that created the NTZs form part of the Kanan Kay Alliance (www.alianzakanankay.org), a voluntary, multisectoral collaborative network formed by >40 organisations including fishing cooperatives, government agencies, NGOs, research centres and philanthropic foundations with the aim of creating NTZs and encouraging sustainable fishing practices. The Alliance creates dialogue spaces in which conservation initiatives are coordinated. Fishers are active participants in the alliance and thus feel included and more willing to implement the recommendations (Moreno et al. 2016). Before the NTZs were implemented, surveys were conducted to evaluate the perception of fishers towards fisheries, NTZs, and the community-based process (Velez, Alderstein & Wondolleck 2014). Additionally, socioeconomic studies were conducted on the fishing cooperatives (Bobadilla 2014) with the results allowing focussed capacity-building for each cooperatives' needs, including strengthening their internal structure and leadership, allowing them to invest in conservation and sustainable fishing.

It is also possible that the highly lucrative lobster fishery in the SKBR has reduced pressure on the finfish fishery in the past decades making FSA protection more amenable within the traditional fishing grounds; however, to what extent varies in each community and regional stocks of transient spawning fish such as groupers continue to decline (Secretaria de Gobernación 2014). The cooperative in Punta Allen now lands very little fish (10 year average of 3.7 tonnes yr^{-1}), and closing a FSA site to fishing likely had little effect on production. However the cooperative in Punta Herrero continues to exploit the finfish fishery (10 year average of 49.5 tonnes yr^{-1}) to complement their income from lobster and the creation of the marine reserves has required a stronger commitment by the community.

In contrast, Mahahual is the only coastal community in the Mexican MAR without a registered fishing cooperative based in the village. The lack of a cooperative reduces the possibility of collaborative work with the fishing community. Mahahual residents also have a pessimistic view of the future; 68% of residents expect fewer fish in the future and only 12% believe that regulations can change the situation (Cinner & Pollnac 2004). The fact that several conservation initiatives have failed to be successfully implemented in Mahahual (e.g. Amigos de Sian Ka'an 2003) reflects that the scope and target of such projects did not successfully address underlying conditions, unite the community nor look to strengthen socioeconomic factors that could promote successful achievement of conservation goals (Cinner & Pollnac 2004).

Promoting an enabling environment for FSA site protection

Heavy fishing pressure on aggregations is not sustainable (Sadovy & Domier 2005). In all cases, a precautionary approach is recommended (Erisman et al. 2015, Sadovy de Mitcheson 2016). *WS* is often the first to raise conservation concerns and to make management recommendations. However, this raises the question of who is responsible for implementing the conservation measures. Should researchers always make management recommendations? And who is responsible for following them through? Is it time for researchers to become more involved in the implementation of their recommendations? The "knowing-doing gap" has been identified in conservation science and many conservation assessments do not plan for action (Knight et al. 2008). But why is this the case?

Research faculty tenure and promotion at most research institutions are generally dependent on excellence in research, teaching and service. Implementation of research recommendations, including conservation, is not linked with research faculty job security and advancement. Though some institutions are increasingly valuing service learning and societal contributions in the tenure and promotion process (June 2013), there have traditionally been disincentives within academia for cross-disciplinary research and its applications in conservation (Arlettaz et al. 2010, Gibbons et al. 2008; Knight et al., 2008). This is definitely the case in Mexico where the National Council of Science and Technology (CONACYT) can make substantial contributions to top researchers' incomes based on research productivity, defined in terms of publications and grants. Critics of the reward system also argue that it discourages collaboration and more heavily rewards papers published in English (Altbach 2015). These incentives contribute to the implementation gap as the most important research may not be immediately available to local practitioners, or in a language they understand, and academics are not rewarded by their employers for participating in the implementation of their recommendations. Jenkins and Maxwell (2011) urge young faculty to push this issue from the grassroots level, highlighting their conservation contributions in their academic CVs. Collaborative efforts between researchers (who provide the technical expertise) and NGOs (who often provide long-term financial support and continuous presence in fishing communities) are now commonplace and are an effective solution to this problem (Da Fonseca 2003, Hamilton, Potuku & Montambault 2011).

This study further revealed the need for TEK to be accompanied by effective science to guide conservation and management (Hamilton, de Mitcheson & Aguilar-Perera 2012). In those sites in which federal protected area zoning (e.g. SKBR, BCBR, XRNP) occurred before adequate science had been completed (either *WS* or *CS*), FSA sites that were described by TEK alone were not successfully protected. FSAs were subsequently found close to, but not in, NTZs (Table 1). Field verification of FSAs has shown that TEK is not always accurate. Anecdotal information needs to be validated through field observations. In the Mexican MAR, it appears that TEK data were collected before the PAs were zoned but field verifications were not completed to adequately geolocate the FSAs. For example, the management plan for the SKBR (Secretaría de Medio Ambiente y Recursos Naturales 2014) recognises the importance of protecting FSA sites and states that the zoning protects FSAs of grouper and snapper. Unfortunately, despite considerable effort by the fisher *CS* teams, to date, it has not been possible to visually verify these sites and the only confirmed sites are located just outside the NTZs. The management plan acknowledges that information is lacking regarding FSAs and that further studies are required to locate the sites with precision, however rezoning federal protected areas can be a long process. The flexibility offered by the Fish Refuge legal framework allows for bottom-up approaches whereby fishers can directly petition the federal fishing authorities to enact conservation measures. The law was first used in 2012 and fishers feel a great sense of ownership for the NTZs that they proposed and that were ultimately created. Compromises, however, must also be made. The three NTZ have each been established for a minimum period of five years, with options for renewal, modification or removal at the end of the period. This time is too short for recovery of grouper biomass to pre-exploitation levels, with marine reserve design principals recommending permanent reserves (Green et al. 2014) to maximise benefits. However, this was the first time this type of protection was applied to FSA in Mexico and fishers must become familiar with the framework. Preliminary discussions suggest that the fishers are willing to renew the sites (Comunidad y Biodiversidad A.C. unpublished data). An additional benefit, mentioned above, is that modifying the zones to include new information is also more easily accommodated in short-term renewable reserves than with traditional zoning schemes.

Though worldwide FSA protection within NTZs is woefully inadequate (Russell et al. 2014) there are a growing number of successful examples where FSAs have been placed within NTZs with varying methods and levels of local support. A Florida fisherman suggested Riley's Hump in the Florida Keys for NTZ status because it served as a multi-species FSA (Locascio & Burton 2016). Characterization was conducted largely by scientists and the initial local reaction to the closure was hostile. Local residents show growing support after seeing that the protection has effectively fostered fish returning to spawn (DeMaria pers. comm.; Burton et al. 2005). FSA conservation projects in the Solomon Islands have also illustrated the value of combining TEK with citizen science (Hamilton et al. 2012). The community reported declining catches but NGOs stepped in to raise awareness and involve the community in monitoring their resources. This led to the creation of a community-based NTZ at the site. In Belize, eleven multi-species FSA sites were closed in 2003 with full support from fishers, following three years of extensive characterization work conducted in partnership between national and international NGOs, the Government of Belize and fishers as citizen scientists (Heyman 2011).

By contrast, there exist many examples where FSA conservation efforts have been hampered by insufficient community involvement in research. In the Cayman Islands, scientific characterization efforts from the national government's Department of Environment, with support from the international NGO REEF, led to the protection of an important Nassau Grouper FSA, which has since shown impressive recovery (Heppell et al. 2012). However, the scientific efforts for characterization and monitoring did not include most local fishers and thus the fishing community has perceived the closure negatively. Similarly, an important FSA site for groupers and snappers in Alacranes Reef, Yucatan, Mexico, (Aguilar-Perera et al. 2008) was proposed as a 513 km^2 Fish Refuge in 2014. However, this initiative was not conducted in collaboration with local fishers, causing the Regional Federation of Fishing Cooperatives in Yucatan to react with surprise and concern to the lack of consultation, and pressure from the fishing industry has since derailed the proposal.

In conclusion, this study illustrates that involving small-scale fishers as citizen scientists can play an important role in creating an enabling environment whereby fishers support full protection of FSAs in the Mexican MAR. We concur with McKinley, Miller-Rushing and Ballard (2015) that citizen science contributes to natural resource science, management, environmental protection and policymaking. In addition, whilst other factors are important (including underlying socio-economic conditions and awareness-raising efforts) the three-pronged approach including traditional ecological knowledge, western science and participatory citizen science is vital for effective conservation outcomes.

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Table 1. Current status of verified fish spawning aggregation sites in central and southern Quintana Roo.

		Characterization Team and Process					Conservation Outcome	
Fish Spawning Aggregation Site	**Source of Traditional Ecological Knowledge (TEK)**	**Initial field investigation**	**Site Map**	**UVC**	**Documented Spawning**	**Species documented (reference for visual verification)**	**Included within Federal MPA (date)**	**FSA protected within NTZ (date)**
San Juan	Sosa-Cordero et al. 2002	CS	CS	CS	CS	*Epinephelus striatus* *Mycteroperca bonaci* (Franquesa-Rinos and Loreto-Viruel 2006, Fulton et al. 2016)	Y (1986)	Y (2016)
Punta Allen	Sosa-Cordero et al. 2002	CS	CS	CS	CS	*Epinephelus striatus* (Franquesa-Rinos and Loreto-Viruel 2006, Fulton et al. 2016)	Y (1986)	Y (2016)
Punta Herrero	Sosa-Cordero et al. 2002	CS	CS	CS	CS	*Epinephelus striatus* *Mycteroperca venenosa* *Lutjanus analis* *Lutjanus jocu* (Fulton et al. 2016)	Y (1986)	Y (2013)
Mahahual	Aguilar-Perera 1994, Sosa-Cordero et al. 2002	WS	WS	WS	WS	*Epinephelus striatus* (Aguilar-Perera 1994)	N	N
Maya Ha	Aguilar-Perera 1994, Sosa-Cordero et al. 2002	WS*	WS*	WS*	WS*	*Mycteroperca bonaci* *Lutjanus cyanopterus* (ASK and COBI 2010, Fulton et al. 2016)	N	N
Xcalak	Sosa-Cordero et al. 2002, Medina-Quej et al. 2004	WS	WS	WS	WS	*Epinephelus striatus* *Mycteroperca tigris* *Mycteroperca bonaci* (Medina-Quej et al. 2004)	Y (2000)	N
Banco Chinchorro	Aguilar-Perera 1994, Sosa-Cordero et al. 2002, Castro-Pérez, Acosta-González & Arias-González 2011	WS	CS	CS	CS	*Lutjanus analis* (Heyman et al. 2014)	Y (1996)	N

CS: Citizen Science (western science involving local fishers). WS: Academics using western science without fisher involvement. WS*: NGO using western science without local fishers.