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Temporal assessment of the management effectiveness of reef environments: The role of marine protected areas in Brazil

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ABSTRACT

Marine protected areas (MPAs) are being successful in the management of fishing resources and conservation of biodiversity in many parts of the world. The assessment of the management effectiveness provides examples to improve the management of these areas. Thus, this study assessed the management effectiveness of 11 MPAs with reef environments in the coast of Brazil, in the period of 10 years (2005, 2010, and 2015), through the method of Rapid Assessment and Priorization of Protected Area Management (RAPPAM). The questionnaire was also used to address the pressure (activities that affect the MPA in the last 5 years) and threats (activities that can potentially affect the MPA in the next 5 years. From the 11 MPAs assessed, the highest values of pressures and threats were obtained for two areas in the year of 2005 and four areas in 2015 (above 35%). The mean management effectiveness between 2005 and 2015 increased from 55.6% (±8.2) in 2005 to 60% (±11.5) in 2015. However, even with this increase, the mean effectiveness of some MPAs is still below the limit considered ideal for satisfactory management (<40%), and the number of MPAs with good management (>60%) has not changed over time.

1. Introduction

Coral reefs are among the most diverse and productive ecosystems on Earth, and they function as indicators of health and resources for marine environments (Mumby, 2006; Mumby and Steneck, 2008; Xu and Zhao, 2014). Moreover, they provide other services to the population, such as coastal protection against wave action and storm surges, pharmacotherapy, and areas for recreation and tourism (Moberg and Folke, 1999; Diedrich, 2007). However, these environments are suffering increasing degradation around the world, and, according to Wilkinson (2008), human activities are responsible for the destruction of 19% of the coral reefs worldwide, and for putting other 35% under action of some kind of threat of loss in 10–40 years.

The problems related to the presence of human population near reef environments are due to the overexploitation of fishing stocks (Sadovy, 2005; Mumby et al., 2006; Newton et al., 2007; Jackson, 2008), the traffic of vessels, with the consequent stranding and shedding of substances at the sea (Chabanet et al., 2005; Game et al., 2008; Ramirez and Lozano, 2014), the presence of invader exotic species, which leads to a loss of biodiversity because of competition for habitat and food (De Paula and Creed, 2004; Morris et al., 2010; Sammarco et al., 2010), and tourism, which causes degradation in the reefs (Leão and Kikuchi, 2005; Mumby and Steneck, 2008; Hilmi et al., 2012).

Furthermore, the entering of sediments and organic matter into marine environments, because of the misuse use of the soil, deforestation, and burnings, raise the concentration of nutrients in the water, especially nitrogen and phosphorous, and it is one of the main sources of degradation of reefs in the world (Fabricius, 2005; Wooldridge, 2009; Wagner et al., 2010; Loiola et al., 2013). Besides, the deforestation and burning of fossil fuels also act by altering the chemistry of the water, due to the increase of CO_2 in the atmosphere, which elevates the water acidity, reduces the amount of calcium available in the environment for the reef constructors, calcareous algae and others, which directly influences the development of the carbonate structures of these individuals and the construction of reefs (Sabine et al., 2004; Cao et al., 2007; Silverman et al., 2009; Sarmento et al., 2015).

The creation of marine protected areas (MPAs) is important to limit the degradation of reef environments (Aronson and Precht,

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2006; Mumby, 2006), support the recovery and stabilization of the functional reef groups (Doyen et al., 2007), and provide areas with no-take recourses (Wantiez et al., 1997; Shanks et al., 2003). However, protected areas (PA) worldwide are facing a series of problems, such as visitor impacts, inadequate management planning, unsustainable resource use, inadequate research, and low law enforcement (Leverington et al., 2010). Moreover, there are problems related to the non-creation and non-implementation of management plans (Worboy et al., 2006; Robles et al., 2007; Lu et al., 2012), the land issues of the protected areas, the scarcity of basic infrastructure and of employees active in the elaboration of policies and conservation strategies (Medeiros and Young, 2011).

In view of these problems, studies that assess the management effectiveness of marine protected areas are essential to provide useful information to managers and decision-makers who manage protected areas (Medeiros, 2006; Day et al., 2012; Schiavetti et al., 2012). The evaluation of management effectiveness is essential for the PAs since it improves the planning strategies by means of priority criteria (Margules and Pressey, 2000). Izurieta-Valery (1997) defines the management effectiveness as “a set of characteristics, actions, attitudes, capacities, and specific competencies that allow a protected areas to satisfactorily perform the function and meet the objectives for which it was created.” To guide this effectiveness evaluation process, the World Commission On Protected Areas (WCPA), in 1995, created a table that could serve as reference for the creation of assessment methodologies (Hockings et al., 2000).

Among the methods of assessment of effectiveness, one of the most accepted is the Rapid Assessment and Priorization of Protected Area Management (RAPPAM) (Ervin, 2003a), as it allows a global analysis of the management effectiveness, identifying the strengths and weaknesses of it and analyzing the pressures and threats (Leverington et al., 2010). The questionnaire is one of the few that covers all six elements of the WCPA: context, planning, inputs, process, outputs, and outcomes (Hockings et al., 2000). This methodology has already been applied in South Africa (Goodman, 2003), Spain (Corral, 2010), Taiwan (Lu et al., 2012), China, Russia, and Bhutan (Ervin, 2003b), totaling more than 53 countries and 1.600 protected areas in the world (Leverington et al., 2010). In the present study, we investigated the effects of the pressures and threats, and assessed the management effectiveness of 11 protected marine areas in Brazil for a period of 10 years.

2. Materials and methods

2.1. Study area

The National Action Plan for the Conservation of Coral Reefs (PAN Corals) defined the priority areas for conservation in the coast of Brazil (Castro et al., 2016) and selected to the research all federal marine protected areas that participated in the questionnaire of Rapid Assessment and Priorization of Protected Area Management (RAPPAM) applied by the Chico Mendes Institute for Biodiversity Conservation (ICMBio) and by the World Wide Found from Brazil (WWF-Brasil) in the years 2005 and 2010, totalizing 11 MPAs (Fig. 1), divided into four categories of the International Union for Conservation of Nature (IUCN) (Table 1).

2.2. Sample design

The RAPPAM questionnaire created by Jamison Ervin (2003a) and applied in this work has 96 questions for the year of 2005, 101 for 2010, and 115 for 2015, divided into 5 topics and 14 modules, plus a profile of MPA and the list of pressures and threats. In 2005, 2010, the RAPPAM questionnaire was applied by the ICMBio and WWF-Brasil in marine and land protected areas of Brazil, with the data available at the website of WWF-Brasil (2015) and the questionnaire available in Ogana et al. (2012). We used this website to obtain the data of the 11 marine protected areas analyzed. The information related to the questions, the answers, and who provided them are available at http://observatorio.wwf.org.br/unidades. The application of the questionnaire in the years of 2005 and 2010 took place through workshops, with the participation of managers and environmental analysts of the federal protected areas of Brazil. Between the application in 2005 and 2010, the ICMBio and WWF-Brasil modified the wording of some questions of the questionnaire without altering the focus of the questions (Ogana et al., 2012).

The questionnaire in the year of 2015 was applied for the same 11 MPAs. However, it presented some modifications in writing, with the questions being changed for marine reality, as this is a questionnaire elaborated to be applied to marine protected areas with reef environments (Supplementary Material Table 1). This modification consisted of including 14 new questions, distributed in 7 modules, and altering the list of pressures and threats affecting the MPAs, now with 14 impacting activities, based on the proposed modifications, chiefly by Corral (2010), who was the only researcher to date to modify the RAPPAM questionnaire for application only in protected marine areas. This questionnaire was answered only by the manager of the protected area, through the Google survey tool, between April and August 2015, and an initial contact with the managers was made to explain the methodology of the questionnaire. When the manager did not answer all the questions, they were forwarded, via e-mail, making it possible to solve any doubt that existed in filling out the questionnaire. If the manager informed that he had no knowledge and/or information to answer a given question, it would be removed from the score analysis of the questions.

2.3. Data analysis

Table 2 shows a list with the pressures (activities that caused impacts in the last 5 years prior to application of the questionnaire) and threats (activities that may cause impacts in the next 5 years after application of the questionnaire) for the MPAs in the years of 2005, 2010, and 2015. The pressures and threats are analyzed according to the scope, impact, and permanence of the occurrence, with scores ranging from 1 to 4, according to the intensity of each activity. The score obtained in these 3 categories was multiplied successively to inform the degree of each pressure and threat in the respective MPA, and can reach a maximum value of 64 points for each activity.

To check the criticality of pressures and threats in the questionnaires applied in 2005, 2010, and 2015, the sum of the total scores of pressures and threats in each MPA for each year was carried out. This value was divided by the maximum possible score for each questionnaire (1024 in 2005 and 2010, and 896 in 2015), to obtain in percentage the criticality of the pressures and threats of each MPA.

To assess the significance of the differences between the 4 activities present in all survey questionnaires (construction of infrastructure, tourism and recreation, waste disposal, and exotic species) we used a permutation multivariate analysis of variance (PERMANOVA, Anderson, 2001), with the Euclidean distance, to verify the differences of the joint activities per year, and the Kruskal-Wallis to test whether the variables showed significant differences between the years. In addition, we also made an analysis between the degree of threat in 2015 and the biological importance of each MPA, to verify which areas need greater attention from management.

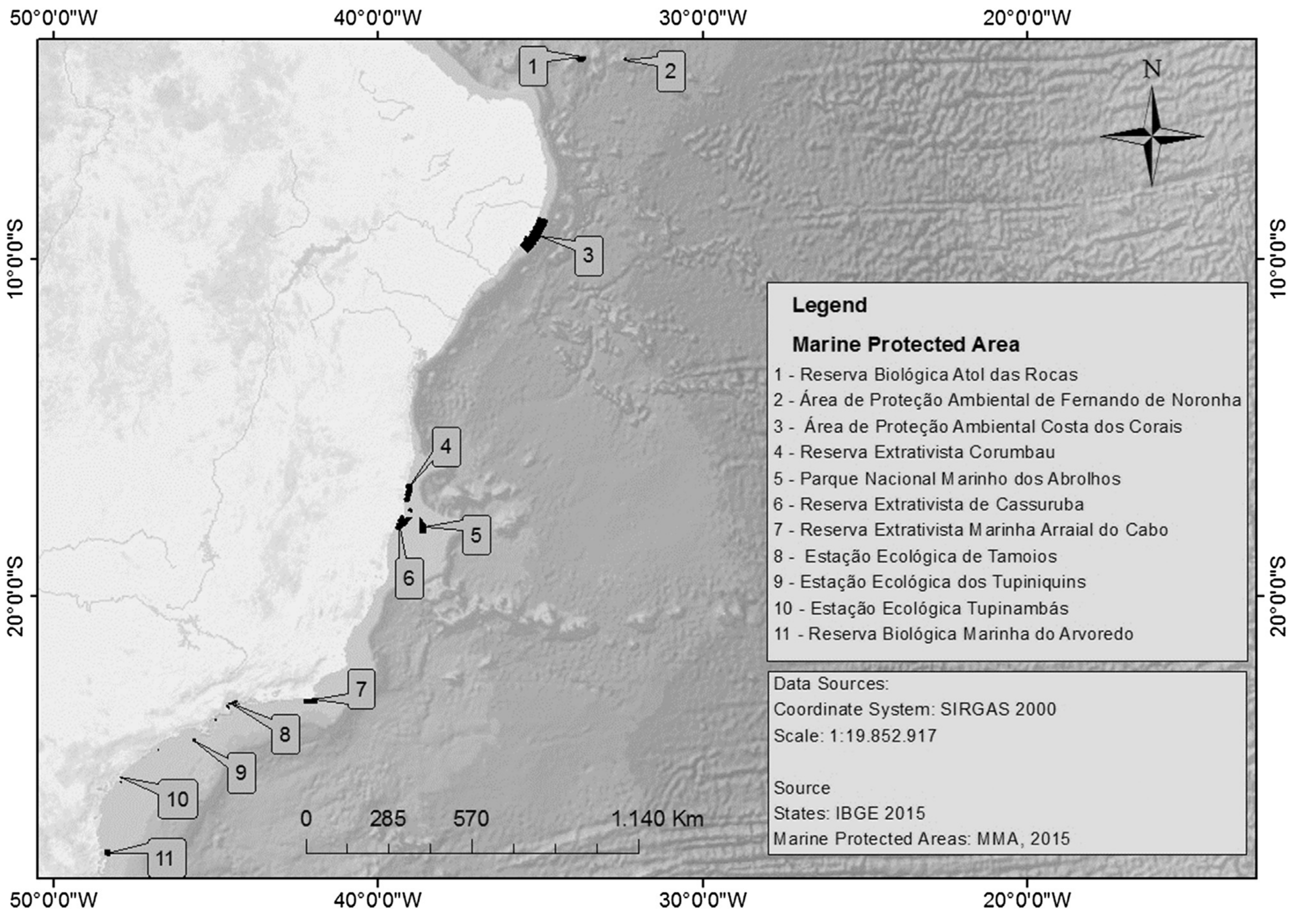

Fig. 1. Coast of Brazil with the marine protected areas analyzed in the study.

Table 1
Marine protected areas covered by this analysis, acronyms used throughout the text, categories to which they belong at the International Union for Conservation of Nature (IUCN), year of creation, and area in hectare (ha).

Nomenclature	Marine Protected Area	IUCN	Year of creation	Area (ha)
MPA1	Reserva biológica Atol das Rocas	Ia	1979	36,249.00
MPA2	Área de Proteção Ambiental de Fernando de Noronha	V	1986	93,000.00
MPA3	Área de Proteção Ambiental Costa dos Corais	V	1997	405,946.00
MPA4	Reserva Extrativista de Corumbau	VI	2000	89,500.00
MPA5	Parque Nacional Marinho dos Abrolhos	II	1983	91,255.00
MPA6	Reserva Extrativista de Cassurubá	VI	2009	100,768.00
MPA7	Reserva Extrativista Marinha Arraial do Cabo	VI	1997	56,769.00
MPA8	Estação Ecológica de Tamoios	Ia	1990	700.00
MPA9	Estação Ecológica Tupinambás	Ia	1986	43.00
MPA10	Estação Ecológica dos Tupiniquins	Ia	1987	28.00
MPA11	Reserva Biológica Marinha do Arvoredo	Ia	1990	17,600.00

The assessment of the topics and modules of the RAPPAM questionnaire was made through the responses given to the questions, which presented four options of answers (yes, mostly yes, mostly no, and no), with the score ranging from 0 to 3, with 0 for no and 3 for yes (Table 3). All the questions, modules, and topics of the questionnaire carry the same importance and weight for the assessment of the management effectiveness of the MPAs.

To determine the percentage of effectiveness of each module of the questionnaire, we made a relation between the high score of each module and the score obtained through the informed replies. To obtain the effectiveness of the topics of the questionnaire, we made the percentage average of the modules inserted in each topic. To assess the management effectiveness in the marine protected area, we made a percentage average of the modules 6 to 16 (totalizing 11 modules). This obtained percentage was compared to the default values to find out in which situation of management is each MPA in each year (<40% - low level; 40–60% - medium level; >60% - high level).

Analysis of variance (ANOVA) was used to verify the difference in effectiveness values between the MPAs and between the years of analysis. The effectiveness values were separated according to the protection categories, in full protection (Ia and II), and sustainable use (V and VI) of the IUCN, and according to the decades of creation (1970–1980 and 1990–2000). T-test was used to verify whether there was difference between the protection categories and between the decades of creation. For the construction of the

Table 2
Pressures and threats applied in the RAPPAM questionnaire for the years 2005, 2010, and 2015.

2005 and 2010	2015
Construction of infrastructure	Construction of infrastructure
Tourism and recreation	Tourism and recreation
Waste disposal	Waste disposal
Invasive exotic species	Exotic species
Hunting	Illegal hunting or fishing
Fishing	
Urban sprawl	Urban sprawl and Presence of populations
Presence of human populations	
Seminatural processes	Climate change
Collection of non-timber products	Aquaculture
Land use conversion	Industrial fishing
Mining	Recreational fishing
Pasture	Traditional fishing
Logging	Fishkeeping
External influences	Vessel traffic
Fires of anthropic cause	Terrigenous influences

Table 3
Topics, modules, and number of questions, for the years 2005, 2010, and 2015, in the Rapid Assessment and Priorization of Protected Area Management (RAPPAM) questionnaire (More information about questionnaire used on 2005/2010 in Ogana et al. (2012) and a Supplementary Materials for 2015).

Topics	Module	Number of Questions		
		2005	2010	2015
Context	3. Biological Importance	10	9	9
	4. Socioeconomic Importance	10	9	9
	5. Vulnerability	9	10	11
Planning	6. Objectives	5	6	7
	7. Legal Support	5	5	5
	8. Design	6	7	9
Inputs	9. Human Resources	5	5	5
	10. Communication and Information	6	6	6
	11. Infrastructure	5	5	6
	12. Financial Resources	6	6	9
Processes	13. Planning	5	5	10
	14. Decision-making Processes	6	8	7
	15. Research and Assessment	6	7	9
Results	16. Results	12	13	13
TOTAL		**96**	**101**	**115**

similarities measure and the Principal Coordinates Analysis (PCoA), we used the Gower's distance, with the purpose of exploring the relations between the responses of MPAs in the three years surveyed.

The analysis of similarity (ANOSIM) was used to verify whether the differences between the responses of the questionnaires were significant between the years. When appropriate, pairwise comparisons were used to elucidate the degree of dissimilarity between the groups. To explore the relations between the modules of the applied questionnaires and the MPAs in the years surveyed, we employed the Principal Component Analysis (PCA). We also tested the correlation between the topics of planning and results and between the topics inputs and results. We also analyzed the dispersion between the management effectiveness and the sum of the pressures and threats of each MPA, to verify whether there was correlation between the effectiveness values and the pressures and threats in each year. The statistical analyses were performed using the programme PAST 3.08 (Hammer et al., 2001).

3. Results

3.1. Pressures and threats

Each pressure and threat ranges from 0 to 64 points, reaching a total of 640 points in 2005, in which there are only 10 MPAs, and 704 points for the years 2010 and 2015, with 11 MPAs analyzed. The smallest value obtained was 0 points to the pressures and threats of urban sprawl and pasture in the year 2005, 0 points for the pressure and threat of urban sprawl in the year 2010, and 12 points for the pressure of fishkeeping and 24 points to the threat of aquaculture in the year 2015.

According to the degree of pressure and threat, the most impactful activity in 2005 and 2010 was fishing; in 2015, it was illegal hunting or fishing regarding pressures and exotic species regarding threats. The activities mentioned for all marine protected areas as pressure and threat in 2005 and 2010 were also fishing, and in 2015 the pressures were illegal hunting or fishing and traditional fishing, and the threats were illegal hunting or fishing, exotic species, climate changes, and vessel traffic.

The analysis of the criticality of the pressures and threats allows one to note that, with the exception of MPA1 and MPA3, all other MPAs presented a higher pressure and threat to 2015, and in this questionnaire the list of activities was modified to be applied to marine areas (Fig. 2). MPA1 was the only one that presented a research period without pressure or threat (in 2010).

The Permanova applied to the four activities present in all the years of research (construction of infrastructure, tourism and recreation, waste disposal, and exotic species) did not detect significant difference between the years for the pressures ($F = 0.6083$; $p > 0.05$) or threats ($F = 0.9706$; $p > 0.05$). The Kruskall-Wallis' test also did not detect any significant difference between the years for any of the pressures ($p > 0.05$), but detected difference in the threats to the waste disposal activity ($p < 0.05$), and the Mann-Whitney's test indicated this difference between the years 2005 and 2015, with the observation of an increase of the quantity of waste between these years.

The assessment between the Biologic Importance (module 3 Table 3) of the MPA and the degree of threat, in 2015, made it possible to identify that MPA3 and MPA5 present a high biological importance and a high degree of threat for years to come, and should therefore have greater attention from the federal government in its management.

3.2. Management Effectiveness

The analysis of the management effectiveness for the protected areas over the 10 years of study allowed us to observe that the MPA2, in 2010, was the only one that showed low effectiveness value (38.0%) and the MPA1, in 2015, the one that showed the greatest effectiveness value of management (80.6%) (Fig. 4). MPAs 1, 2, and 3 presented an improvement of effectiveness value from 2005 to 2015. Only the MPAs 4, 6, and 10 showed an increase of the effectiveness value of management over time, with the MPA6 almost doubling the effectiveness value from 2010 to 2015. MPA7 was the only one that showed reduction in effectiveness over the years, from 67.2% in 2005 to 48.8% in 2015. In analyzing the management effectiveness per year, we obtained an average value of 55.6% (±8.2) for the year 2005, 52.5% (±10.2) for 2010, and 60% (±11.5) for 2015, and the MPA4 was the only one that was below this average value in all years of research.

However, despite the numerical differences, the Anova did not identify a significant difference to the effectiveness value when compared the MPAs between themselves nor when compared the years between themselves ($p > 0.05$), indicating that the effectiveness values did not differ statistically over the years and neither between the protected areas.

The effectiveness value of marine protected areas was divided between the IUCN's protection categories, such as full protection (Ia and II) and sustainable use (IV and VI) (Table 4). These data show

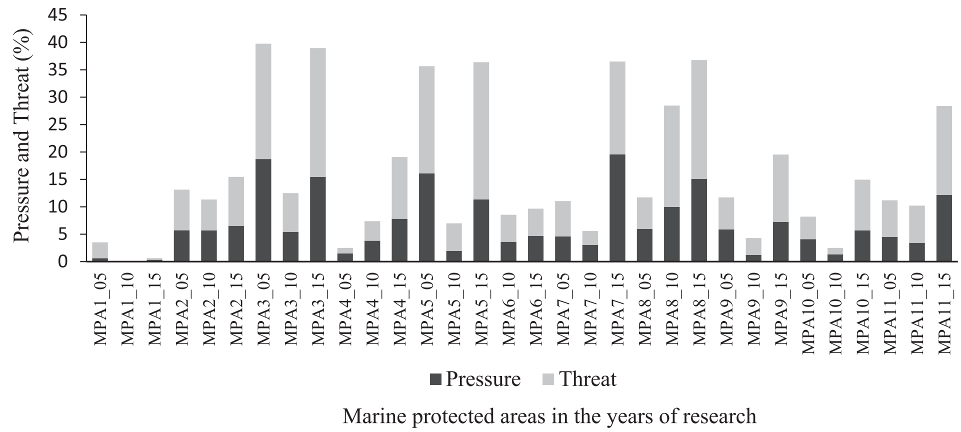

Fig. 2. General criticality of pressures and threats, in percentage, observed in the federal protected areas in the 2005, 2010, and 2015 cycles.

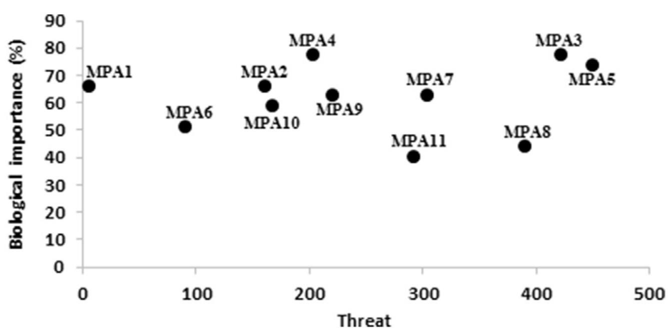

Fig. 3. Dispersion of threats versus biological importance of 2015 for the analyzed MPAs.

between 1970 and 1980 and 6 MPAs between 1990 and 2000 (Table 4), and in this analysis, only in the year 2015 a value really different to the average effectiveness of MPAs was obtained. The T-test indicated no significant difference between the effectiveness values of full protection and sustainable use ($p > 0.05$) and neither between the data of effectiveness per year of creation ($p > 0.05$).

The Principal Coordinate Analysis (PCoA) to the questions of the RAPPAM questionnaire showed that the two first axes explain together 34.82% of data (23.00 and 11.82, respectively) (Fig. 5). This analysis identified two groups, with the years 2005 and 2010 to forming one group, and the year 2015 forming another one. The PCoA revealed a grouping of data in the years 2005 and 2010 for the MPA1, MPA7, and MPA4. The MPA3 and MPA5 show greater proximity of data between 2005-2015 and 2010–2015, respectively.

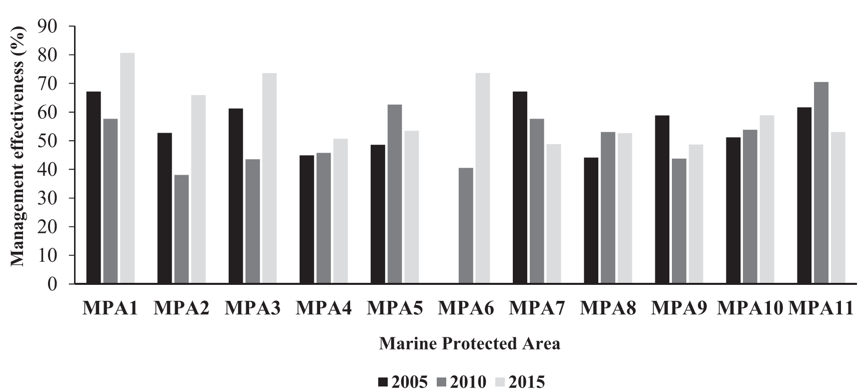

Fig. 4. Management effectiveness of the 11 protected areas over the years of research (above the dashed line - high effectiveness; between the dashed and continuous line - medium effectiveness; below the continuous line - low effectiveness).

that, with exception of the year 2010, the MPAs of sustainable use showed greater average effectiveness value. The effectiveness value was also divided according to the year of creation, totalizing 5 MPAs

Table 4
Average of the management effectiveness by IUCN's protection category and by year of creation.

	Full Protection	Sustainable use	1970–1989	1990–2009
2005	55,3	56,5	55,7	55,8
2010	56,9	45,1	51,2	51,8
2015	57,9	62,5	61,5	58,8

To test whether the addition of the 19 new questions was responsible for the distancing of data in 2015 (Fig. 5), we made a PCoA without these questions. As we did not observe difference in the distribution of data in this new PCoA, we can infer that the inclusion of the questions was not responsible for the distancing of data in 2015.

Through the Anosim's test to the answers of the questionnaire, we verified that there is a significant difference ($p < 0.05$) between the years of the research, and the Bonferroni's post-test verified that the difference occurred between the year 2015 with the years 2005 and 2010. In analyzing the difference between the MPAs, the removal of MPA6 was required, because it only had two years of

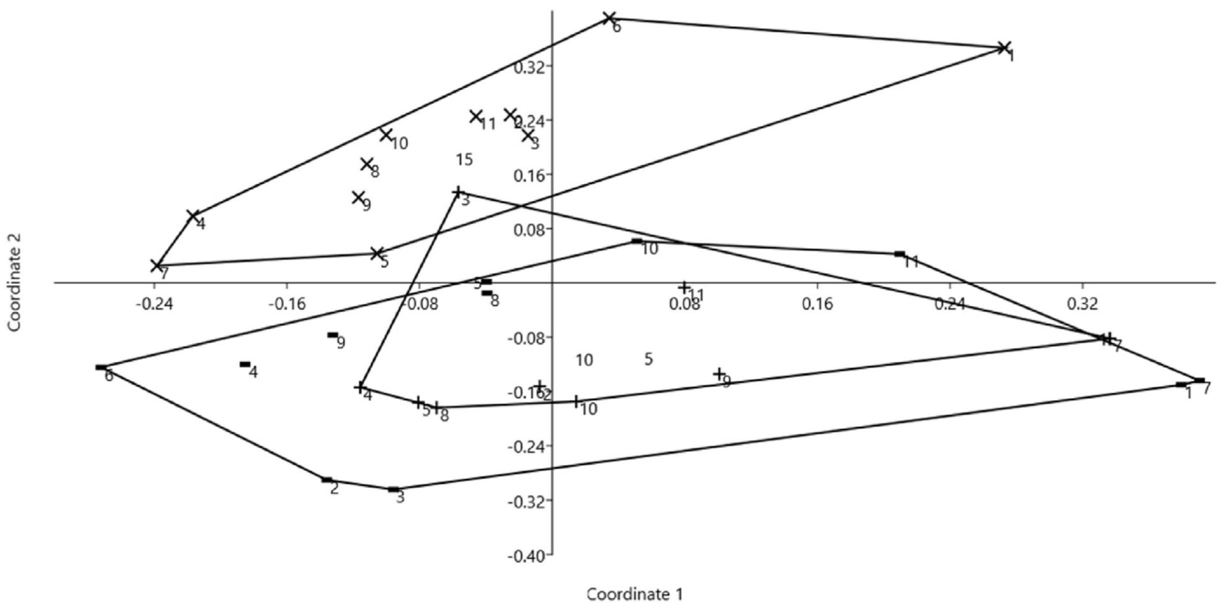

Fig. 5. PCoA of the distribution of the 10 areas over time, with polygons separating each year of the research (+: 2005; −: 2010; X: 2015; 1. MPA1; 2. MPA2; 3. MPA3; 4. MPA4; 5. MPA5; 6. MPA6; 7. MPA7; 8. MPA8; 9. MPA9; 10. MPA10; 11. MPA11).

sampling. The Anosim's test showed there is a significant difference ($p < 0.05$) between the MPAs, but the Bonferroni's post-test could not detect which marine area had difference, probably because there were only three samples for analysis in each MPA.

The analysis of the questionnaire modules per year allowed us to observe that in 2005 and 2010 the lowest average values were obtained for the modules of Human Resources (module 9 Table 3) (36.7% ± 21.1 and 35.2 ± 13.0), Infrastructure (module 11 Table 3) (38.0% ± 22.9 and 33.3% ± 15.5), and Financial Resources (module 12 Table 3) (41.7% ± 17.4 and 23.7% ± 10.6). It is worth noting that MPA2 was the only one that contributed to the reduction of the three modules cited in 2010. The year of 2015, in turn, had a general improvement in the values of the modules, with Financial Resources (module 12 Table 3) (42.1% ± 21.2) and Infrastructure (module 11 Table 3) (45.5% ± 15.3) showing the lowest values.

The Principal Component Analysis (PCA) of the questionnaire modules showed that 49.22% are explained by the first two axes (34.28% and 14.94%, respectively) (Fig. 6). Axis 1 is more influenced by the modules of Management Planning (module 13 Table 3) and Research and Assessment (module 15 Table 3), and the axis 2 is more influenced by the modules of Human Resources (module 9 Table 3), Socioeconomic Importance (module 4 Table 3), and Financial Resources (module 12 Table 3), demonstrating that these are the modules responsible for the greater effectiveness value of management in the MPAs. In turn, the marine protected areas that are more influenced by axes 1 and 2 are the MPA1, MPA2, MPA3, and MPA6, in 2015, showing greater effectiveness value of management out of all MPAs in the studied years.

Among the topics of the questionnaire, the topics of Planning was the one that most contributed to raise the level of management effectiveness, influencing mainly the MPA4 in all the years of research, and the topic of Inputs was the one that most contributed to the reduction of management effectiveness, influencing mainly the MPA2 in 2010.

For a strategic management of the MPAs, an understanding of the relations between the topics of Planning, Inputs, and Results is necessary. Thus, Fig. 7 shows a weak positive correlation between the topics of Planning and Results ($R^2 = 0.28$) and between the topics of Inputs and Results ($R^2 = 0.15$).

A scatterplot between the management effectiveness and the sum of the pressures and threats of each MPA may indicate the existence of a correlation between these two variables, pointing out that MPAs with greater effectiveness value would present lower pressures and threats. Fig. 8 shows the accumulation of pressures and threats and the management effectiveness of the years 2005, 2010, and 2015, with the respective trend lines, and we did not observe correlation between these two variables for any of the years (2005 − $R^2 = 0.0001$; 2010 − $R^2 = 0.009$; 2015 − $R^2 = 0.27$). Fig. 8 also shows that the MPAs that present high management effectiveness and low level of pressure and threat to the year 2015, and that, consequently, can better perform their function of protecting the reef environments and the organisms that inhabit it are the MPA1, MPA2, MPA6, and MPA10.

4. Discussion

4.1. Pressures and threats

This study proposed a new list of pressures and threats, with activities that occur in marine and coastal environments, since the RAPPAM questionnaire applied in 2005 and 2010 used for these areas the same list of activities applied to terrestrial areas. From Table 2, it is possible to highlight the activities that are exclusively terrestrial and were applied to marine environments in 2005 and 2010, and the sum of the degrees of each activity impacting in 2005 and 2010 indicated that urban sprawl (0 and 0), pasture (8 and 8), logging (30 and 30), hunting (45 and 53), and fires of anthropic cause (68 and 93) showed the lowest scores to pressures and threats, respectively, of a maximum total of 1344 points for these two years together.

This shows that in those years the analysis of the activities that influenced the MPAs presented an erroneous panorama for managers, with few activities actually affecting these areas. With the change of this list for 2015, we were able to verify a situation closer to reality, with the MPAs scoring in more activities, and consequently presenting a higher value of pressure and threat (Fig. 2). Among the 14 activities proposed in 2015, to pressures and threats, only aquaculture (use of aquatic environment for the farming of

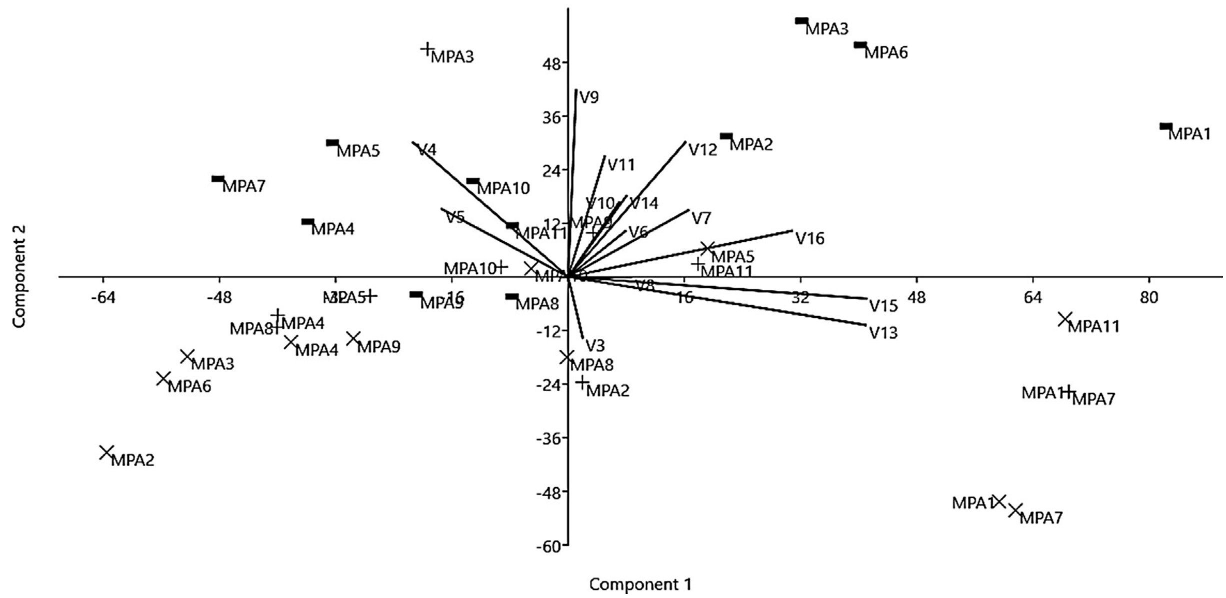

Fig. 6. PCA of the questionnaire modules with the 11 marine protected areas over time (+: 2005; X: 2010; −: 2015; V3. Biological importance; V4. Socioeconomic importance; V5. Vulnerability; V6. Objective; V7. Legal support; V8. Design; V9. Human resources; V10. Communication and information; V11. Infrastructure; V12. Financial resources; V13. Management planning; V14. Decision-making process; V15. Research and assessment; V16. Results).

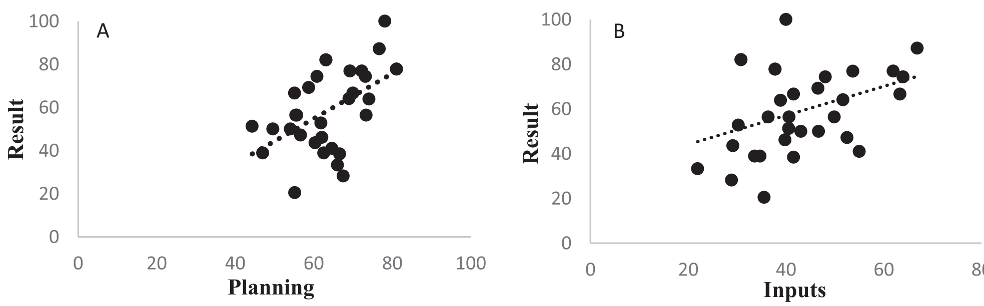

Fig. 7. Dispersion with the values of the topics of planning and results (A) and inputs and results (B) for the MPAs in the years of analysis.

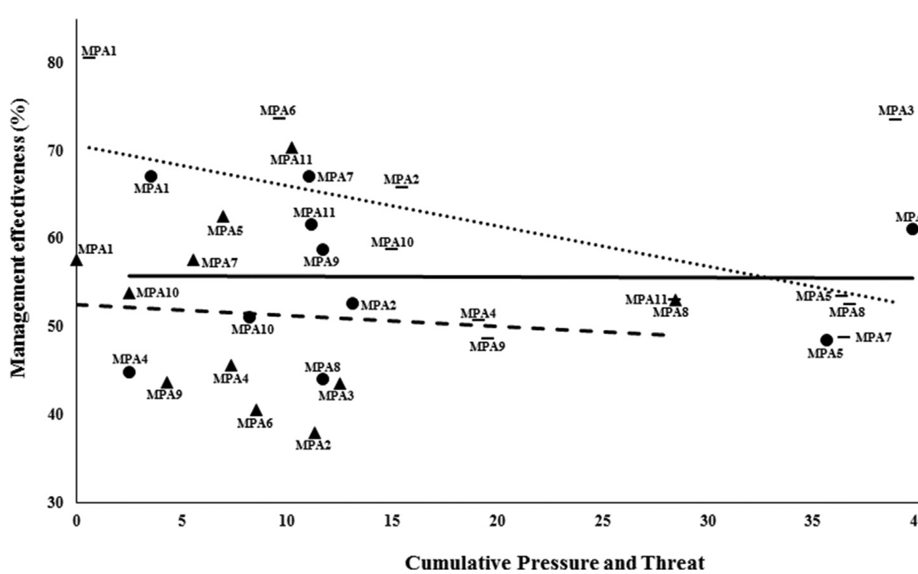

Fig. 8. Dispersion between the management effectiveness and the accumulated value of pressures and threats with trend line (2005: ●, 2010: ▲, 2015: -; entire line: 2005, dashed line: 2010, dotted line: 2015).

fish, shellfish, etc.) (14 and 24, respectively) and fishkeeping (catching of fish and other organisms for aquariums) (12 and 32, respectively) showed a degree far below the total of 704, indicating that the activities proposed in the new questionnaire are more consistent with the reality of marine protected areas in Brazil and around the world.

The threats cited by all the managers as being the most important for marine protected areas with reef environments in Brazil are illegal hunting or fishing, exotic species, climate change, and the traffic of vessels. Corral (2010) compared these results with those found around the world, applying the RAPPAM questionnaire in a MPA with reef environments in Spain, and identified global warming, the outpouring of oil from vessels, and the introduction of exotic species as the most impacting activities. According to Giglio et al. (2016), in the Abrolhos Marine National Park, in Brazil, other pressures on reef environments are marine tourism over the reefs in the diving areas that cause great problems to coral reefs, and according to Burke et al. (2011), in the Great Barrier Reef in Australia, these pressures are the runoff of silt, nutrients, and contaminants from agricultural, urban, and industrial areas.

Marine waste are a widespread problem in the world, encompassing several compounds, such as plastics and other synthetic materials, mainly from terrestrial sources (Morishige et al., 2007; Pichel et al., 2007; Costa et al., 2009; Ryan et al., 2009). Ocean currents act as efficient sources of waste dissemination, especially plastics, with these waste acting as “rafts” to the spread of invasive marine organisms (Barnes and Milner, 2005; Gregory, 2009), and the same levels of waste of very industrialized areas in remote oceanic islands have been found (Barnes and Milner, 2005). Besides, the abandoned fishing waste continues to capture, accidentally, marine organisms, such as fishes and crustaceans, leading to their death (Matsuoka et al., 2005). These fishing waste can destroy coral reefs through the drag by wave action, by entanglement in organisms, and by suffocation, abrasion, and fragmentation of the habitat and of species (Donohue et al., 2001; Asoh et al., 2004; Chiappone et al., 2005).

The National Action Plan for the Conservation of Endangered Species (PAN), developed in Brazil, aims to identify species threatened with extinction and the pressures and threats that affect the environments, to develop conservation strategies to prevent the extinction of these species, being under the responsibility of ICMBio (Castro et al., 2016). PAN Corals identified as pressures and threats the occupation and overuse of coastal areas, leading to the destruction of habitats, contamination by pollutants, and sedimentation resulting from watershed drainage and mining (Castro and Pires, 2001; Leão et al., 2003); the collection/fishing that is illegal, excessive, or in critical areas (Floeter et al., 2006; Kitahara, 2009); and the effects of climate change, whose changes in these environments affect their ecological functionality (Buddemeier et al., 2004).

Through the analysis of pressures and threats provided by managers, we found that the threats with high degree, pointed in 2005, by the managers, to happen over the next 5 years, were exactly the same pressures with high degree in 2010, such as fishing, tourism and recreation, invasive species, and external influences. This highlights the knowledge regarding the problems and future threats on the part of managers, and this information may serve as a tool for the conservation of these environments.

In this perspective, the threats identified by the managers that may occur between 2015 and 2020 and that require greater attention on the part of managers, government, and public and private organizations are, by degree of impact, exotic species, climate change, waste disposal, illegal hunting or fishing, traditional fishing, and vessel traffic. In turn, the marine protected areas that deserve greater attention are the MPA7, MPA8, and MPA11, which present high criticality regarding pressures and threats (Fig. 2), and MPA3 and MPA5, which, in addition to high criticality, have high Biological Importance (module 3 Table 3) value (Fig. 3). In this way, the efforts of PAN Corals for the conservation of coral reef environments and the species that exist in this environment must be focused mainly in these areas, which could pose problems in the future because of the high rates of pressures and threats to which they are subjected.

It is worth pointing out that these threats identified by the managers, in 2015, were cited in more than 80% of the MPAs, indicating, according to Ervin (2003b), a systemic problem of marine protected areas, rather than problems in the individual management of each area. Lu et al. (2012) propose some measures that can be adopted by PAN Corals to improve the management of the system of marine protected areas, such as monitoring the level of pollution, of invasive species, and of anthropogenic interventions in these areas; regularly reviewing the management plans; strengthening the support and participation of the residents of local communities and of tourism agencies in the conservation of the coral reefs. Leão and Kikuchi (2005) also point to the need for improvement in the measures of protection of Brazilian MPAs, identifying the priorities for action, such as awareness campaigns about the conservation of coral reefs, strengthening in control programs and assessment of reefs, and showing the managers the need and efficiency of management practices before more coral species are lost.

4.2. Management Effectiveness

Among the 11 MPAs analyzed in the 10-year period, MPA1, in 2015, showed the greatest effectiveness value, with the topic of Processes showing the greatest value (76.8%) for this area, and the MPA2, in 2010, was the one that showed the lowest effectiveness value (38%), with the topic of Inputs showing the lowest value (21.9%) (Fig. 4). In analyzing the topics in the 11 MPAs of the study and in the 10 years of research, Planning was what most contributed to raise the level of management effectiveness and Inputs were what most contributed to the reduction of this effectiveness value. This shows a problem between the structuring of a protected area (with the goals well clear, a legislation that protects and supports these areas, and a design that favors the conservation of the species and the environment), and its real capacity to develop its functions of protection, since, without human and financial resources, without infrastructure, and without means for obtaining information and distribution of these data for all involved, it is impossible to have a good development of management processes and achieve good results in its conservation, and this same relation is found by Kurdoğlu and Çokçalişkan (2011) in Turkey.

Analyzing the modules of the topic of Inputs, Financial Resources (module 12 Table 3), Infrastructure (module 11 Table 3), and Human Resources (module 9 Table 3) were the ones that obtained the lowest average values in the 10 years of analysis among the 11 modules in the calculation of management effectiveness (35.6%, 38.3%, and 44.4%, respectively), contributing to this topic to be the lowest among the assessed topics. Goodman (2003), in his study of the peninsula of KwaZulu-Natal, in South Africa, Tyrlyshkin et al. (2003), in Russia, and Batsukh and Belokurov (2005), in Mongolia, also found the topic of Inputs as the one that presented the lowest value among the themes that compose the assessment of management effectiveness. According to Leverington et al. (2010), low scores on questions about financial and human resources are a global standard for protected areas, both marine and terrestrial ones, which was also observed for the MPAs with reef environments in the coast of Brazil, with the financial resources in a critical situation, since the Ministry of the Environment has one of the five smaller budgets between the ministries and, besides, is suffering with funding cuts since 2006 (Bernard et al., 2014). In turn, the module of Human Resources (module 9 Table 3) is influenced by the reduction in financial resources, through the lack of hiring and training of employees, and this module is considered a great problem in many protected areas in the world (Lacerda et al., 2004; Corral, 2010; Spathelf, 2010; Gerhardinger et al., 2011; Lu et al., 2012; Magris et al., 2013).

Within the topic of processes, the module of Planning of management (module 13 Table 3) deserves greater attention, since the establishment of the management plan of the protected area is a basic criterion for the conservation of any environment (Leverington et al., 2010; Gerhardinger et al., 2011), and is the main mechanism to plan and respond to the pressures and threats in the area (Mathur et al., 2015). In Brazil, many protected areas still do not have the Management Plan (Veríssimo et al., 2011), and in this study, 4 MPA, in 2010, and 3 MPAs, in 2015, had no plan, which influenced negatively this module. Furthermore, the module of Research and Assessment (module 15 Table 3) also deserves attention, because of the growing number of researches carried out in many MPAs that do not meet the needs of knowledge of the area, and often the results are not made available to managers (Lacerda et al., 2004). Goodman (2003), in his study in South Africa, found a positive correlation between the topics of Inputs and Results and between Planning and Results, indicating that a better planning and increased inputs in the protected area could result in best practices in management. However, in this study, this correlation was not observed among the topics (Fig. 7), and a justification for this result was not identified.

In the world, Tacón et al. (2006) found the effectiveness value of management of 51.6% to 37 protected areas of Chile, and the topic of Inputs and module of finances showed lower value in this country; in Taiwan, Lu et al. (2012) found the effectiveness value of 55% in five protected areas analyzed, with the topic of Processes and the module of planning showing lower values. Corral (2010), in his study on the marine protected areas of Spain, found the effectiveness value of management, for the seven areas analyzed, of 57.4%, with the topic of Results showing lower value, and the effectiveness value of 55.5% to the Isla de Alborán, a MPA with reef environments. In this study, the average effectiveness value of management for the 11 marine protected areas ranged from 55.8% in 2005 to 60% in 2015, and this value may have been influenced by the time of activity of the manager in the function, by the time of creation of the MPA, and by the category to which it belongs, according to IUCN.

Regarding the time of activity of the manager in the function, from the 11 MPAs surveyed, only MPA1, MPA4, MPA5, MPA8, and MPA10 had the same manager answering the questionnaire in 2010 and 2015, and only MPA1 and MPA5 had the same manager answering from the year 2005–2015. It is worth noting that the managers of the MPA2 and MPA6 had only five and six months in the function, respectively, when they answered the questionnaire. This change and the short time of activity of the manager in the function over the years of application of the questionnaire may induce a misperception regarding the evolution of the MPA in these 10 years of research, as noted for MPA2, according to information of residents and researchers who inhabited the island during this period. Regarding the analysis by IUCN's protection categories, with the exception of the year 2010, the MPAs of sustainable use (IV-VI) presented a higher effectiveness value of management (Table 4), mostly because of the topic of Planning, which involves questions such as problem solving with the surrounding community, land situation, and acceptance of the goals and limits of the area protected by population, and these situations are most difficult to be solved in areas where it is not allowed any kind of direct use of natural resources (I-III). And regarding the effectiveness value according to the decade of creation, in general, we did not observe a difference between the values (Table 4), due to the year of creation of the responsible authorities for legislating and administer the environmental issue and the protected areas in Brazil, with the Ministry of the Environment (MMA) being created in 1985 (Brasil, 1985) as Ministry of Urban Development and Environment, the Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) in 1989 (Brasil, 1989), and the Law that establishes the National System of Nature Conservation Units (SNUC) in 2000 (SNUC, 2000).

According to the PCoA and Anosim's test, it was noted that there is a difference between the answers of the year 2015 to the years 2005 and 2010 (Fig. 5), indicating that, overall, an improvement occurred in the effectiveness value from 2005 to 2015, and this is also observed through the average value of each year, because of an improvement in MPA1, MPA2, MPA3, MPA4, MPA8, and MPA10, in the modules of Human Resources (module 9 Table 3), Infrastructure (module 11 Table 3), and Results (module 16 Table 3), and in the topics of inputs and results. This improvement in the effectiveness value is due to the goal of the Convention on Biological Diversity (CBD) that determined, until the year 2020, the deadline for creating more protected areas and that they must be effective in the protection of their environments (Weigand et al., 2011). In Brazil it was also observed this trend of increase in the number of MPAs, and according to Gerhardinger et al. (2011) there are approximately 62 marine protected areas under federal administration. As to the effectiveness of these areas in protecting the environment, this is evidenced by the improvement in the effectiveness value of management from 2005 to 2015. This is due to, among other reasons, the creation of a responsible authority only for the protection of species of wild fauna and flora, and the establishment of SNUC, the ICMBio, in the year 2007 (Brasil, 2007), and the investment from national and international companies in the marine protected areas, as is the case of MPA1 and MPA3, which have, since 2010, perpetuity to assist in the development of activities of protection and management of the area, sponsored by Toyota do Brasil Foundation.

The scatterplot of the management effectiveness with the sum of the pressures and threats to which each MPA is subjected did not identify a positive correlation in the years 2005, 2010, and 2015 (Fig. 8), indicating that, in this study, the MPAs with high effectiveness value not necessarily present less pressure and threats, as it can be observed mainly for MPA3 in the years 2005 and 2015. Goodman (2003), in their study conducted in five protected areas in Taiwan, observed an inverse correlation between these two variables, and according to them the distant location and the geography of the protected area influence the type of pressure and threat that this area will suffer, and this, in turn, will influence the management effectiveness. This inverse correlation, however, must be considered for the establishment of priority areas for the conservation of reef environments inside the PAN Corals, on the part of ICMBio and the government, since the MPA3, MPA5, MPA7, and MPA8, in 2015, showed high value of pressures and threats, in addition to the fact that some of these areas have high biological importance and may, in the future, suffer a reduction in the effectiveness value of management, which will influence the conservation of reef environments and their dependent bodies.

5. Conclusion

Erroneous knowledge about the pressures and threats affecting the marine protected areas with reef environments can affect the entire management. Thus, we found with this study that marine areas must be subjected to pressures and threats different from those of terrestrial areas, being specific to portray the reality of that environment. Before this new list applied in 2015, the activities that represent a greater threat for the next 5 years, cited by all managers, are illegal hunting or fishing, exotic species, climate change, and the traffic of vessels, with MPA7, MPA8, and MPA11 deserving greater attention because they suffer great impact by pressures and threats, and MPA3 and MPA5 because, besides the threats they suffer, they have great biologic importance.

Regarding the effectiveness value of management, the year 2015 presented a significant difference with the other years, with this year being the only one that presented a high effectiveness value (60%). Among the topics of the questionnaire, Planning was what showed the greatest effectiveness value of management and Inputs were what showed the lowest value. Among the modules, the ones that most contributed to raise the effectiveness value were the Objectives and Decision-making Processes, and to reduce the value, were the Financial Resources, Infrastructure, and Human Resources. In turn, the relation between the sum of pressures and threats and management effectiveness, to the year 2015, allowed us to identify that 4 MPAs can perform their function of protecting the reef environments.

It is worth noting some problems identified by researchers and raised by other authors regarding the methodology of the RAPPAM questionnaire. The limitations of the questionnaire include the lack of an in-depth analysis of data that can be reflected in an analysis only of the final effectiveness value, ignoring the questions with negative answers, which deserve more attention by the management; the non-existence of an option "I am not aware/I do not know" in the questionnaire; and the doubly negative questions, which induce a misunderstanding on the part of the respondent. Besides, there is the problem of the quality of the information provided by the managers and administrators, which need to be adequate to provide sufficient data for analysis, being difficult to verify them, which can affect the effectiveness value of management of each marine protected area assessed.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2017.03.015.

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