

## ARTIFICIAL REEFS FOR MARINE AND FRESHWATER FISH MANAGEMENT IN BRAZIL: RESEARCHERS PROFILE AND ACADEMIC PRODUCTION OVER THE 1990-2010 PERIOD

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### ABSTRACT

Publication from 1990 to 2010 on the use of artificial reefs for fish management in Brazil was analyzed to characterize the researchers' profile and describe the temporal evolution of scientific production. Ten top Brazilian researchers working with artificial reefs for fish management were recorded, with most studies being performed in shallow marine waters of the Southeastern region. The ratio between the total amount of articles published exclusively about artificial reefs and the total number of publications varied considerably among researchers, ranging from less than 1 to 100% of scientific production devoted to artificial reefs and fish. A total of 33 articles was published at indexed periodicals whereas 44 publications were retrieved from vehicles of limited circulation (i.e. grey literature). Of these scientific articles, 27 referred to marine systems while only six studies focused on freshwater reefs, with most articles (87.5%) being published in journals of impact factor lower than 2.0. Despite the apparent increased production of indexed articles with impact factor after 2000, our results overall stressed that scientific studies on artificial reefs for fish management are too recent in Brazil, still demanding much further research to approach the levels achieved by the most productive countries on this research theme.

**Key words:** artificial habitats, fish assemblages, marine, freshwater, management

### RESUMO

Publicações de 1990 a 2010 sobre o uso de recifes artificiais no manejo da ictiofauna no Brasil foram analisadas para caracterizar o perfil dos pesquisadores e descrever a evolução temporal da produção científica. Dez pesquisadores trabalhando com recifes artificiais aplicados ao manejo de peixes foram registrados e a maioria dos estudos foi conduzida em áreas marinhas rasas da região Sudeste. A razão entre a quantidade total de artigos publicados exclusivamente sobre recifes artificiais e o número total de publicações variou consideravelmente entre pesquisadores, de menos 1 até 100% da produção científica dedicada sobre recifes artificiais e peixes. Um total de 33 artigos foi publicado em periódicos científicos indexados, enquanto 44 publicações foram obtidas de veículos com circulação limitada (i.e. literatura cinza). Dos artigos científicos, 27 se referiram ao ambiente marinho enquanto apenas seis focaram sobre recifes continentais, sendo a maioria (87,5%) publicada em revistas com fator de impacto inferior a 2,0. Apesar do incremento na produção de artigos indexados e com fator de impacto após 2000, nossos resultados enfatizam que estudos científicos sobre recifes artificiais para o manejo pesqueiro são recentes no Brasil, exigindo pesquisa adicional para se aproximar dos níveis atingidos pelos países mais produtivos sobre este tema de pesquisa.

**Palavras-chave:** habitat artificiais, ictiofauna, marinho, água-doce, manejo

### INTRODUCTION

Artificial reef can be defined as synthetic or natural structures that are deployed in aquatic environments for multiple purposes, but especially to increase the availability of submersed habitats and to enhance the attraction and/or production of biological resources (Bohnsack *et al.* 1991, Seaman 2000). Because of the great resemblance of the artificially deployed structures with natural hard substrates, such as rocky or coral reefs, the term "artificial reef" has

been largely applied for marine systems (Seaman and Sprague 1991). On the other hand, "artificial shelter" or "artificial habitat" have been often applied for freshwaters, where the structures are also used to mimic soft habitats, such as floating macrophytes and other types of aquatic vegetation. Regardless of the ecosystem, marine or freshwater, artificial reefs are broadly recognized as tools for fishery management, since they can provide new substrate for the settlement of invertebrates and other prey species, furnish shelter for forage and juvenile fish, attract and concentrate

species of commercial interest, and also inhibit predatory fishing practices (Seaman 2000, Baine and Side 2003, Santos *et al.* 2008b).

The first initiatives of using artificial reefs to attract and concentrate fish resources date back to the Neolithic period (9000-5000 BC), when logs and rocks were submerged to create new fishing areas at African coast (Santos and Passavante 2007). Since then, the use of artificial reefs for fishery purposes has greatly increased, becoming now a worldwide practice, but especially applied for shallow marine ecosystems in Japan, USA and Occidental Europe, and in North American lakes and reservoirs (Baine and Side 2003, Bolding *et al.* 2004, Santos *et al.* 2011). Despite their long empirical use by fishermen and their growing utilization within the non-academic fields (Conceição *et al.* 2007a), the scientific researches on the use of artificial reefs as tools for fishery management in Brazil are poorly known, mainly for freshwaters, where this initiative is even more recent. Therefore, a compilation of the existing studies with artificial reefs could be very useful, not only to understand the potential of habitat manipulation programmes on management and conservation of fish assemblages in Brazil, but also to comprehend the contribution of those studies within the national academic scenario.

This work carried out a pioneering literature review of existing publications on the use of marine and freshwater artificial reefs for attraction and management of fish resources in Brazil. For practical purposes, this study was split into two sections: 1) Researchers profile, in which the main characteristics of the national academics developing studies related to the theme are provided; 2) Bibliographic production, a full inventory on all the published articles between 1990 and 2010, as available in the major online academic databases. It is expected that, rather than to profiling the scientific scenario on the use of artificial reefs as fishery management tool in Brazil, this study can also contribute with important information to guide future researches on the manipulation and conservation of Brazilian fish assemblages through the use of submerged structures.

## MATERIAL AND METHODS

### RESEARCHERS PROFILE

Analyses of the curriculum vitae, as available in Plataforma Lattes (<http://lattes.cnpq.br>), provided the

basis to select the major Brazilian researchers performing studies on the use of marine or freshwater artificial reefs to attract or manage fish. From this online database, data on institutional affiliation (institutional name and origin – public or private); study environment (marine and/or freshwater); name and duration of research project; support of funding agencies, total number of published articles on any subject; number of published articles on the use of artificial reefs for fish attraction or management. Only those researchers that matched the following requisites – institutional affiliation longer than 12 months; current or past participation in carrying out research projects; and at least one published article on the study theme – were selected to further analyses on academic profile. The Plataforma Lattes database was last searched on October 2010.

### BIBLIOGRAPHIC PRODUCTION

Publications related to artificial reefs and Brazilian fishes were first retrieved from Plataforma Lattes, using the same database available for the researchers who followed the selection criteria previously assigned in the Researchers Profile section. Then, further searches were performed in the ISI Web of Science<sup>SM</sup> Science Citation Index Expanded (<http://apps.webofknowledge.com>) and SCOPUS ([www.scopus.com](http://www.scopus.com)) databases using “artificial reef and Brazil”; “artificial habitats and Brazil”; and “artificial structures and Brazil” (both in English and Portuguese), as key words. Finally, the same key words were searched in Google website aiming to collect as much as information on this study subject between 1990 and 2010. All electronic databases were last searched on December 2010.

Although all collected information (i.e. not only indexed and non-indexed articles regularly published in indexed scientific journals but also the grey literature, which means those non periodical publications of restrict circulation) have been regarded in the analysis of the temporal evolution of publications, only those papers published in scientific journals were investigated in details. Those papers were thus classified as of opinion (review) or experimental (primary research) article; refereed to marine and/or freshwater system; and assigned to the Brazilian regions that they covered. The impact factor (IF) is a bibliometric index that reflects the amount of times an article is cited by a set of journals that integrate a platform. Here, the IF of

each journal that published a paper on artificial reefs and Brazilian fishes were assessed through the 2009 Journal Citation Reports (JCR) platform (<http://science.thomsonreuters.com/techsupport/>), to standardize the comparisons among articles.

## RESULTS AND DISCUSSION

### RESEARCHERS PROFILE

In total, 10 leading researchers were identified as attending to the pre-established criteria for the development of research on the use of artificial reefs in attracting and management of fish resources (Table 1). Among them, five researchers performed its activities in marine environment, four in continental systems, and only one worked in both environments.

The world's longest practice of deploying structures in shallow coastal waters together with the broad stretch (e.g. ~8400 km) of Brazilian shelf might explain the researchers' preference for marine artificial habitats (Santos and Passavante 2007, Brotto and Zalmon 2008). Despite the more than 6 million hectares of dammed environments (Agostinho *et al.* 2007), our results indicated that the Brazilian reservoirs are still little used for studies with artificial reefs.

The researchers in this study are distributed in almost all regions of the country except the Midwest. The Southeast region held most of the researchers ( $N=5$ ; 50%), followed by the Northeast ( $N=3$ ; 30%) and South and North regions ( $N=1$  for both; 10% each), and except for a single scientist working at private university, all the researchers belonged to public institutions.

**Table 1.** Researcher name, study environment, academic affiliation, time span of the research project (between brackets), total amount of publications and number of articles specifically addressing artificial reefs (AR) and fish assemblages. Data gathered from Lattes Online Database (<http://lattes.cnpq.br>) for the 10 leading Brazilian researchers on artificial reefs. Major funding source: \*public;\*\*private.

RESEARCHER'S NAME (STUDY ENVIRONMENT/INSTITUTION ACRONYM)	RESEARCH PROJECT (TIME SPAN)	TOTAL OF PUBLISHED ARTICLES PER TOTAL OF ARTICLES ADDRESSING AR(%)
Angelo Antonio Agostinho (Freshwater/UEM)	1) Use of artificial habitats for fish recovery and enhancement at impoundments of the Paraná River Basin (2005-2007)*	139:1(0.7%)
Carlos Edwar de Carvalho Freitas (Freshwater/UFAM)	1) Effects of increased environmental complexity on fish communities in lakes of Anavilhanas Ecological Station, Rio Negro (Amazonas) (2006-2009)*	44:4 (9.1%)
Daniel Shimada Brotto (Marine/UVA)	1) Artificial reef programme in the northern coast of the state of Rio de Janeiro (2001-current)* 2) Effects of artificial reefs on fish community at Ilha Grande Bay (1995-1996)*	10:10(100%)
Francisco Gerson Araújo (Freshwater/UFRRJ)	1) Monitoring and management of fish fauna in reservoirs using artificial structures, biotic indicators and ecology of fish (2000-2009)**	115:1(0.9%)
Francisco Manoel de Souza Braga (Freshwater/UNESP)	1) The study of artificial reefs as fish attractors in the reservoir of UHE Volta Grande, rio Grande (MG-SP) (1999-2001)**	99:1(1.0%)
Ilana Rosental Zalmon (Marine/UENF)	1) Artificial reef programme in the northern coast of the state of Rio de Janeiro (1995-current)*	36:15(41.5%)
Luciano Neves dos Santos (Freshwater and Marine/ UNIRIO)	1) PISCES project: Assessment, recovery and management of fish assemblages at LIGHT impoundments (1998-2004)* 2) Use of artificial habitats for fish recovery and enhancement at impoundments of the Paraná River Basin (2005-2007)* 3) Artificial reef programme in the northern coast of the state of Rio de Janeiro (2009-current)*	14:3(21.4%)
Raimundo Nonato de Lima Conceição (Marine/UFC)	1) Marambaia artificial reef project (1993-2000)* 2) Marine artificial reefs (1997-1998)* 3) VIVAMAR Project (2000-2002)*	11:5(45.5%)
Reynaldo Amorim Marinho (Marine/UFC)	1) Marambaia artificial reef project (1994-current)* 2) VIVAMAR Project (2000-2002)*	6:1(16.7%)
Vicente Vieira Faria (Marinho)/UFC	1) Marine Artificial Reefs (1996-1998)*	15:3(20.0%)

In addition to host the country's major financial centers and the higher availability of investment and sources to foster research, the Southeast, compared to other regions, also yields most research institutions, concentrating, therefore, most researchers on artificial reefs. The first experiments on artificial reefs officially supported by public institutions were also recorded in this region in the 1980s, aiming the exclusion of shrimp trawling. However, because of those experiments were not coordinated by academic researchers at that time, they did not result in scientific publications. Since the mid-1990s, the North Fluminense State University (UENF) has carrying out initiatives using tires and concrete units to create areas for the exploitation of fishery resources, with several articles published on this subject (Zalmon *et al.* 2002, Santos *et al.* 2011). The Federal University of Rio de Janeiro (UFRJ) performs studies on the potential use of obsolete oil platforms and former hydrographic ships as artificial reefs within the Campos Basin (Alencar *et al.* 2003). The Southeast also had the highest number of researchers and research institutions related to the use of artificial reefs in freshwater, especially the Federal Rural University of Rio de Janeiro (UFRRJ) and the Federal University of Rio de Janeiro State (UNIRIO). Of the 10 leading Brazilian researchers that conducted studies on artificial reefs for fish management, only three researchers (all from the Southeast) have continuously performing studies and actively publishing articles on this theme.

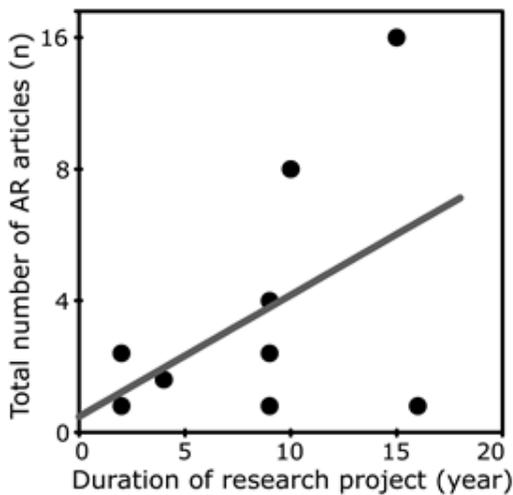
In the Northeast, the use of artificial structures for fishing is an ancient practice, commonly used by traditional coastal communities (Conceição *et al.* 2007a), which probably led local researchers to develop practices on the use of artificial reefs to attract and concentrate fish. The first scientific research promoted by a public agency in this region was recorded at the Ceará state in 1994, as an initiative of the Study Group on Artificial Reefs (GERA), linked to the Laboratory of Marine Sciences, Federal University of Ceará (UFC). In this study, modules of tires were deployed on the sea bottom in order to create new fishing areas and increase fish production in the northeastern states (Santos *et al.* 2010c). After this initiative, other states in this region started to work with artificial reefs for fishery improvement, which, in addition to the tire modules, wrecked ships have been used for both commercial and recreational purposes (Santos *et al.* 2010c). There was no record of

freshwater reef projects conducted by Northeast researchers.

The other regions contributed individually with 10% or less of researchers working on artificial reefs and fish, apparently for different reasons. The lower availability of research institutions and fundings together with the greater degree of conservation of natural habitats could have limited the interest on artificial reef studies in the North. It is noteworthy that, in the North, the single project on artificial reefs recorded was carried out in freshwater. Not only the same reasons accounted for the probable causes of no leading researcher on artificial reefs in the Midwest, but also the inland position of this region, in which the lack of direct access to the sea precluded any study on marine artificial reefs. The lower interest by artificial reef researchers in the Southern region, an area with a broad coastline (~1,250 km) and several impounded rivers and large reservoirs, cannot be, however, fully understood. In the South, the Paraná state is the prominent in studying artificial reefs, and since the creation of the Marine Artificial Reefs (RAM) Programme in 1997, many structures have been deployed on the coast for fishery enhancement and management. Currently, more than 2,000 artificial reef modules are placed on the continental shelf of Paraná state in order to enhance the upwelling water effects and fish larvae production at the Paranaguá-Cananéia estuary (Alencar *et al.* 2003). Surprisingly, we cannot find any leading researcher on the use of marine artificial reefs for fish management in the South, and the single top researcher that carried out projects in the Southern region focused only on freshwater reefs.

In this study, we identified 10 scientific projects on artificial reefs conducted by Brazilian researchers, equally distributed between marine and freshwater systems ( $N=5$  for both). Most projects were supported by public funding agencies ( $N=8$ ; 80%), with a mean duration of 5.5 years. Seven projects were undertaken simultaneously between 1990-2000, with a trend of an increase in the number of projects carried out within 1999-2000 ( $N=7$ ) in relation to the 1993-1996 period ( $N=5$ ). Up to nine artificial reefs projects were performed at the same time between 2000-2010, although six projects were more usual for most of the period. These results suggest a greater investment in research on artificial reefs after 2000, probably through the increment of partnerships between universities and non-governmental institutions, which have fostered

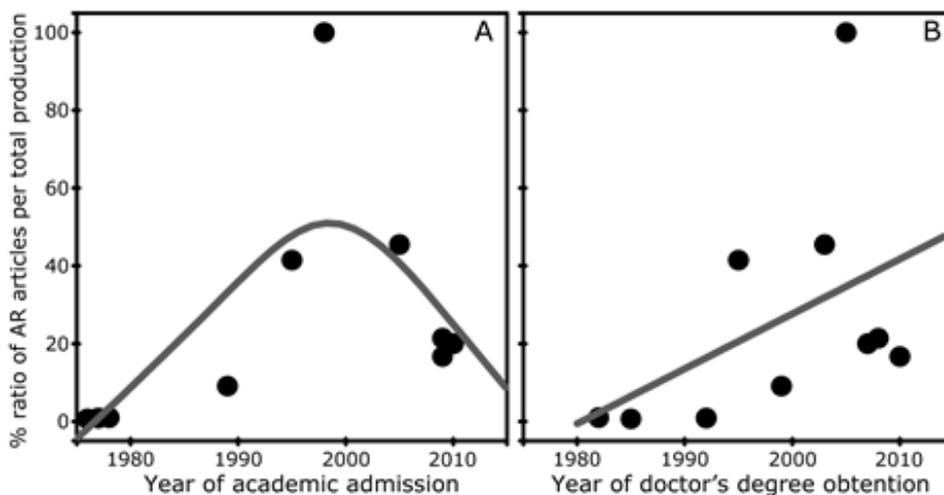
several projects for deployment and management of marine artificial reefs, especially in those states bordered by the sea and between the Parana and Rio Grande do Norte stretch (Santos *et al.* 2010c). The positive linear relationship of the total number of published articles on artificial reef for fish management with the duration of research projects on this same theme (Fig. 1) indicates that, however, prioritizing single long-term and continuous studies are more profitable than short-term and generally more occasional projects, when bibliographic production is the major target.



**Figure 1.** Relationship of total number of articles on artificial reef for fish management (AR) with the duration\* of scientific project conducted by the 10 major Brazilian researcher on this same theme. Lines are the generalized additive models selected by the Akaike information criterion. \* only projects with the longest time span were considered for projects with temporal overlapping of the same researcher.

Off the five research projects carried out in freshwater environments, only two studies were not undertaken exclusively in lentic areas of impoundments. The first project on freshwater artificial reef is dated from 1999, being developed by the São Paulo State University (UNESP), and the latest in 2006, by the Federal University of Amazonas (UFAM). Research on freshwater artificial reefs are still recent and with minor tradition in Brazil. There is not a single research project on this theme being conducted at the present time (i.e. the most recent project was finished in 2009).

The ratio between the total amount of articles published exclusively about fish associated with artificial reefs and the total number of publications varied considerably among researchers, ranging from 100% of scientific production devoted to artificial reefs to less than 1% dedicated to this subject. Researchers in which  $\leq 10\%$  of their total publications were devoted to study artificial reefs and fish have comparatively a long history (i.e. admission as staff at a research institution before 1980) of simultaneous publications on diverse ichthyological areas within the national scenario, leading to a dilution of the importance of papers on artificial reefs in relation to their total amount of publications (Fig. 2-A). Researchers that spend intermediate effort to publish on artificial reefs (i.e. between 10% and 20% of their total production) have acceded near the end of 1980s and 2010s into their affiliated institution, whereas those who have primarily dedicated their academic production on artificial reefs (i.e.  $\geq 40\%$  of the total published) became officially staff between 1995 and 2005.



**Figure 2.** Relationship of the percent ratio of artificial reef (AR) articles per total academic production with: (A) year of researcher admission as staff at the university; (B) year of doctor's degree obtention by researcher. Lines are the generalized additive models selected by the Akaike information criterion.

These trends suggest that research on artificial reefs represents more a matter of momentaneous opportunity than constituting a main area of work and research. However, the positive linear relationship between the percent of total production dedicated to artificial reefs and the year in which the researcher obtained its PhD degree (Fig. 2-B) indicates that articles on artificial reefs are comparatively more important to junior researchers (i.e. doctor's degree obtained in 1995 or latter) than to senior scientists. Taking into account the National plan of reforming and improvement of public universities through the REUNI Programme (Plan for Reorganization and Expansion of Federal Universities), which has been carried out since 2008, it is expected an increase of the publications on artificial reefs, assuming that the researchers would keep the similar devotion to this subject as those academic colleagues who have obtained the PhD degree after 1995.

#### BIBLIOGRAPHIC PRODUCTION

A total of 77 publications on marine and/or freshwater artificial reefs were identified between 1990 and 2010, in which 33 (43.4%) accounted for articles published in indexed scientific magazines released at regular intervals (Table 2). The other publications ( $N=44$ ; 56.6%) correspond to issues of limited circulation, considered as grey literature. Off the total published as scientific papers, 27 articles are related to marine environment and six refer to freshwater habitats. Southeast is the region of Brazil with the largest number of published articles on artificial reefs ( $N=20$ ; 60.6%), followed by the Northeast ( $N=8$ ; 24.2%) and southern ( $N=3$ ; 9.1%). This pattern becomes even more evident when considering only the articles on marine habitats, where the Southeastern region contributes with one article for every 110 km of coastline, the Northeastern with one article for each 413 km, and the Southern with 1:626 for the article per coast stretch ratio. The dominance of published articles on artificial reefs in the Southeast region seems to obey the pattern observed for the greater number of researchers affiliated with research institutions in this region and, thus, is also related to the major incentives of the research funding agencies in this zone.

Despite ranking as the Brazilian region with the longest coastline (i.e. 3.300 km), few articles on artificial reefs were published in the Northeast, indicating an unexploited potential for developing researches on this subject. The main personnel and entities performing research on marine artificial reefs in the Northeast are

located in Ceará, Rio Grande do Norte and Pernambuco states. The southern region, in addition to having the smallest Brazilian coastline, did not contribute significantly with the amount of published papers in the use of artificial reefs by local researcher. Surprisingly, there are many projects and initiatives on artificial reefs and fishes in this region, highlighting the RAM Programme, in the Paraná coast, with records of approximately two thousand reef units deployed and several socio-economic and ecological benefits (Jardeweski and Almeida 2005; Hackradt and Hackradt 2009).

Only six papers were recorded on freshwater artificial reefs, as a result of research carried out exclusively in reservoirs in the South and Southeast (Table 2), revealing a lower contribution from the other three Brazilian regions to such studies. Although one researcher was identified as faculty of a public institution of teaching and research in the North, his published articles on freshwater artificial reefs are not associated with this region. The complete lack of publications on freshwater artificial reefs in the Northeast region might be associated with two causes: i) the historical interest on marine artificial reefs, thus concentrating most attention and funding of northeastern researchers and non-academics; ii) the inherent difficulties to conduct studies on artificial reefs in the many ephemeral water bodies that are typical of the predominant arid zones on the interior of this region. In general, researches on freshwater artificial reefs are relatively recent in Brazil, and the few related publications recorded until 2010 prevented further accurate analysis on the temporal evolution of published articles.

In total, five publications addressed opinions and reviews on the practical application of artificial reefs in fisheries science, two of these articles focusing on the use of submerged structures to increase the fishing yields and for general coastal management at the national level (i.e. articles 24 and 29, published, respectively, in 2007 and 2010). The other three opinion papers have also covered topics related to coastal management, but in a more regional scale, dealing with issues related only to the states of Pernambuco and Ceará (i.e. articles 8, 25 and 27, published, respectively, in 2001, 2008 and 2010). Regarding the total number of publications on artificial reefs, the opinion articles accounted for a significant proportion (i.e. 16% of total production). Because they are based on compilations of primary data resources, those opinion articles can contribute to near the issue "artificial reef and fisheries" among academic communities and non-traditional means of communication.

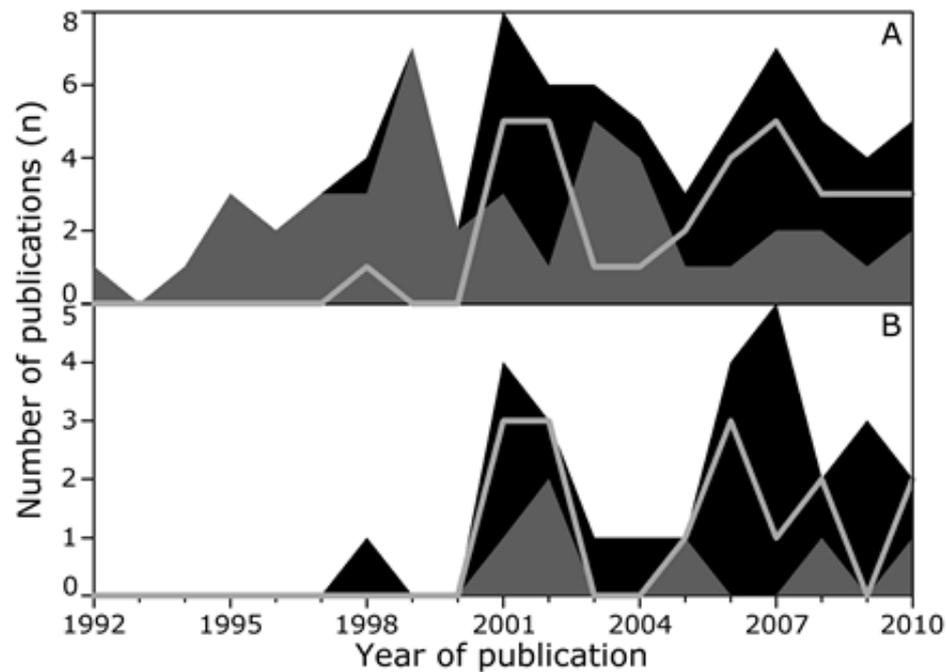
**Table 2.** Scientific publications of Brazilian researchers related to artificial reefs and fisheries resources. The study environment, geographical location and area of installation of artificial reef are also provided.

ENVIRONMENT	GEOGRAPHIC LOCATION	AUTHORS (ARTICLE ORDER)
Freshwater	19°57', 48°25' - 20°10', 47°35'	Braga (2002) (1)
Marine	22°8', 44°05' - 23°5', 44°40'	Brotto and Araujo (2001) (2)
Marine	21°29', 41°00'	Brotto and Zalmon (2007) (3)
Marine	21°29', 41°00'	Brotto and Zalmon (2008) (4)
Marine	21°29', 41°00'	Brotto <i>et al.</i> (2006a) (5)
Marine	21°29', 41°00'	Brotto <i>et al.</i> (2006b) (6)
Marine	21°29', 41°00'	Brotto <i>et al.</i> (2007) (7)
Marine	03°00', 39°23' - 04°06', 37°53'	Conceição and Franklin-Júnior (2001) (8)
Marine	03°17', 38°54' - 03°19', 38°51'	Conceição <i>et al.</i> (2007a) (9)
Marine	03°17', 38°54' - 03°19', 38°51'	Conceição <i>et al.</i> (2007b) (10)
Marine	03°36', 39°21'	Conceição and Monteiro-Neto (1998) (11)
Marine	05°06', 36°19'	Conceição and Nascimento (2009) (12)
Marine	03°00', 39°23' - 04°06', 37°53'	Conceição and Pereira (2006) (13)
Marine	23°32', 45°04'	Cunningham and Saul (2004) (14)
Marine	21°27', 41°00'	Faria <i>et al.</i> (2001) (15)
Freshwater	22°29', 48°34'	Freitas and Petreire-Júnior (2001) (16)
Freshwater	22°29', 48°34'	Freitas <i>et al.</i> (2002) (17)
Freshwater	22°29', 48°10' - 22°44', 48°34'	Freitas <i>et al.</i> (2005) (18)
Marine	21°30', 41°00'	Godoy <i>et al.</i> (2002) (19)
Marine	13°01', 42°00'	Godoy and Coutinho (2002) (20)
Marine	21°27', 41°00'	Gomes <i>et al.</i> (2001) (21)
Marine	21°27', 41°00'	Gomes <i>et al.</i> (2004) (22)
Marine	25°45', 48°20'	Hackradt and Félix-Hackradt (23)
Marine	28°00', 48°33'	Jardeweski and Almeida (2005) (24)
Marine	21°29', 41°00'	Krohling <i>et al.</i> (2006) (25)
Marine	-	Santos and Passavante (2007) (26)
Marine	-	Santos <i>et al.</i> (2008a) (27)
Freshwater	22°42', 43°53' - 22°50', 44°05'	Santos <i>et al.</i> (2008b) (28)
Marine	-	Santos <i>et al.</i> (2010a) (29)
Marine	24°05', 54°00' - 25°33', 54°37'	Santos <i>et al.</i> (2010b) (30)
Marine	-	Santos <i>et al.</i> (2010c) (31)
Freshwater	21°29', 41°00'	Santos <i>et al.</i> (2011b)* (32)
Marine	21°27', 41°00'	Zalmon <i>et al.</i> (2002) (33)

\* article in press when electronic databases were searched

The temporal evolution of publications on artificial reefs and fish management that was produced in Brazil during the 1990-2010 period was showed in Figure 3 (A-B). The first publication on this subject dated back to 1992, but only in non-conventional channels (i.e. grey literature), a media that significantly dominated in number by the year 2000 ( $t_{2,16} = 3.44$ ;  $P = 0.003$ ). While the first scientific article published on this theme was recorded in 1998, the amount of these kinds of papers did not level with those of grey literature until 2001, resulting in no

differences in the number of publications between those two medias per year during the 2001-2005 period ( $t_{2,8} = 0.17$ ,  $P = 0.87$ ). The number of published articles in indexed periodicals remained quite variable throughout the 2000s, but this kind of paper significantly outnumbered the grey literature annually during the 2006-2010 period ( $t_{2,8} = 4.92$ ,  $P = 0.002$ ). Articles published in indexed journals peaked at 2001-2002 and 2006-2007, while lower productivity of that kind of paper was recorded during 1999-2000 and 2003-2004 periods.



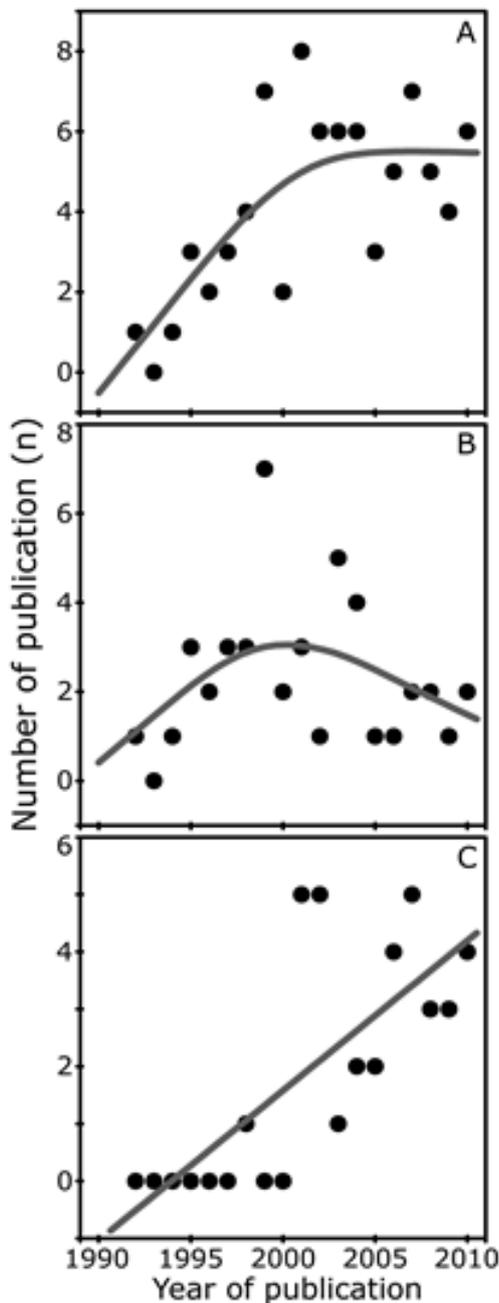
**Figure 3.** Historical evolution of publications on artificial reefs for fish management in Brazil. (A) total bibliographic production (black area); total produced through non-conventional media (i.e. grey literature; dark-grey area) and total of articles published in indexed journals (light-grey line); (B) articles published in indexed journal for marine (black area), freshwater (dark-grey area) systems, and with JCR impact factor (for marine and freshwater artificial reefs together; light-grey line).

The number of publications overall increased linearly with time until 2000, with a trend of stabilization in six publications per year on the average after that (Fig. 4-A). The amount of grey literature and indexed articles also increased linearly until 2000, but while the first decreased gradually after that (Fig. 4-B) the latter continued to rise linearly toward 2010. Those trends suggest an increasing maturity of Brazilian researchers to divulge their findings on artificial reefs and fish management after 2000, abandoning the use of non-conventional media to prioritize publication of scientific articles in indexed journals.

High production of articles on marine artificial reefs were also recorded for 2001-2002 and 2006-2007 periods (Fig. 3-B), denoting the great contribution of studies in this environment to the general patterns found. Those peaks of publication are probably related to occurrence of the 7th and 8th CARAH (International Conference on Artificial Reefs and Artificial Habitats), in 2002 and 2005, respectively, which may have led to increase the number of published articles. The CARAH has also probably contributed to an increase on the impact factor of publications during those periods, given that some oral and poster presentations were retrieved to be published as special issues of indexed international journals. Despite being performed in Brazil in 2009 and

co-organized by Brazilian researchers, the 9th CARAH surprisingly accounted for few contributions for national bibliographic production on artificial reef and fish management (i.e. only a single book chapter by Santos *et al.* (2011a)). These unexpected results may be partially related to the initiative of the 9th CARAH organizers in publishing selected oral and poster presentations in a book, instead of in indexed international journals as often occurred in the previous CARAHs. After 2008, the rate of indexed articles published on marine artificial reefs became constant, with two papers per year, but most of this recent production was concentrated in two or three researchers in the Southeast, publishing especially on artificial reefs deployed in the North coast of Rio de Janeiro state.

Since 2001, published articles on freshwater artificial reefs peaked every two to three years, interspersed by periods of lower productivity (Fig. 3-B). This pattern may be related to the time required by researchers for data acquisition and achievement of the results proposed in the projects. However, it can be also a reflect of the low commitment of researchers with studies on freshwater artificial reefs, as the ratio of the published articles on this subject and the total number of published articles never surpassed 10% per researcher (i.e. ranging from 0.7% to 9%).



**Figure 4.** Relationship of the total number of (A) publications on artificial reef and fish (i.e. grey literature and indexed articles together), (B) bibliographic production through non-conventional media (i.e. grey literature), and (C) indexed articles with time. Lines are the generalized additive models selected by the Akaike information criterion.

Contrasting to their great importance in North America, where a variety of structures has been long deployed into freshwaters for theoretical and applied studies on fisheries management (Bolding *et al.*, 2004), freshwater reefs could be, perhaps, less attractive to Brazilian researchers than those artificial structures placed in marine systems. This possible unattractiveness could be partially explained by the

lower diversity of the associated fish assemblages, the negligible role of fouling organisms, and the faster deterioration of freshwater reefs over time in relation to marine artificial reefs (Seaman and Sprague 1991, Seaman 2000).

Off the 33 articles published in scientific journals, 48.5% ( $N=16$ ) had some impact factor (Table 3), with 13 articles referring to marine reefs and the other three concerning to freshwater structures. However, the averaged impact factor of articles on freshwater reefs (i.e. 2.14) was marginally higher ( $t_{2,14} = 1.96, P = 0.07$ ) than those on marine reefs (i.e. 1.08). Although overall evenly distributed among the categories of the impact factor (Table 3), 87.5% of the articles were published in journals with impact factor lower than 2.0. From 2000 to 2005, eight articles were published in journals with impact factor, while eight articles were recorded for the five following years. The averaged impact factor of these articles throughout the 2000-2010 period increased of 1.10 in 2000-2005 to 1.46 for the next five years. The positive linear relationship of the total number of articles published in indexed journals with time recorded for marine artificial reefs, freshwater artificial reefs, and for both systems, but only those with some impact factor (Fig. 5-A-C), indicate that Brazilian researchers have increased their efforts to publish in scientific periodicals, especially at those of better quality and higher impact factor.

**Table 3.** Impact Factor retrieved from the Journal Citation Reports (JCR 2009) for articles published on fishes associated with artificial reefs in Brazilian waters through the 1990-2010 period.

JCR IMPACT FACTOR	NUMBER OF PUBLICATIONS
< 0.5	5
0.5 – 0.99	3
1.0 – 1.49	2
1.5 – 1.99	4
≥ 2.0	2

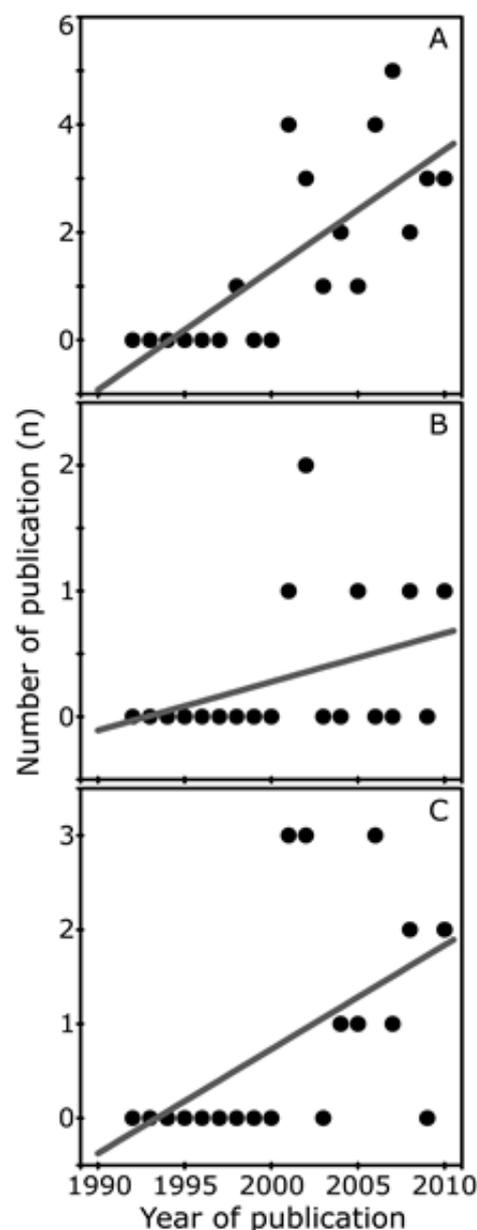
In summary, since the first empirical initiatives conducted by artisanal fishermen at the Northeastern marine coast to the more recent experiments performed by scientific researchers, we detected an advance in the amount and, especially, quality of publications on the use of artificial reefs to fish management in Brazil. In addition to the increasing number of publications, the decade of 2000s can be distinguished from the previous years by a growth on the production of articles at indexed journals, especially those with some impact factor. This progress, however, was slow and in much

lower magnitude when compared to the total amount of scientific articles produced on this theme in the world (i.e. 2.1% and 3.7% off the total, according to ISI Web of Science and Scopus, respectively) or by researchers from USA, Japan, England and some Mediterranean European nations, which have a long history in studying the use of artificial reefs on fish management (Bortone 2006, Seaman *et al.* 2011). Our results also indicated that most published articles are from the Southeastern region, especially on the North coast of Rio de Janeiro state, and focused on marine systems, probably due to the greater amount of researchers and funding opportunity in this zone and to the historical practice of deploying structures in coastal waters. Despite the great availability of propitious areas for deploying artificial reefs, and the applied importance of such kind of habitat manipulation programmes for fish management and conservation, our results overall stressed that scientific studies on artificial reefs and fish are too recent in Brazil, still demanding much further effort to approach the production levels achieved by the most productive countries on this research theme.

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**Figure 5.** Relationship of the total number of articles published in indexed journals with time for (A) marine artificial reefs, (B) freshwater artificial reefs, and (C) both systems, but only those with some impact factor. Lines are the generalized additive models selected by the Akaike information criterion.

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