BIOTA AMAZÔNIA

ARTICLE

DOI: http://dx.doi.org/10.18561/2179-5746/biotaamazonia.v11n3p5-8xx

Reproductive aspects of Caribbean Sharpnose shark *Rhizoprionodon porosus* from Northeastern coast of Brazil

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ABSTRACT

This study aimed to verify reproductive aspects of *Rhizoprionodon porosus* (Poey, 1861) captured by small-scale fisheries on coastal waters from Northeastern of Brazil. Samples were obtained during the dry and rainy seasons between 2015 and 2016. Specimens were sexed, measured (cm ± sd), weighted (g ± sd), eviscerated and had their maturity stages verified. A total of 169 (103 male and 66 females) was sampled between 4 and 30 m depth. It was confirmed three maturity stages: neonate (37.95 ± 3.59 cm Total Length (Lt); 230.02 ± 72.90g Eviscerated Weight (We), juvenile (47.10 ± 2.91 cm Lt; 436.7 ± 79.60g We), and adults (69.15 ±12.29 cm Lt; 1556.08 ± 831.40g We). Males were predominant over females along the year. The negative allometric coefficient for adults suggests an adaptation strategy to reach larger sizes faster, avoiding predation. The size for first sexual maturation was estimated in 57.5 cm Lt. However, over 60% of total samplings corresponded to neonates. The period of reproduction seems to occur continuously with females migrating to shallow waters during the dry season to give birth. The abundance of neonates and some females at late maturity stages indicate fisheries are operating within nursery areas, which might affect recruits in the stock.

Keywords: coastal shark migration; size at first maturity; nursery areas.

Aspectos reprodutivos do tubarão 'cação-frango' *Rhizoprionoson porosus* da costa do Nordeste do Brasil

RESUMO

Este estudo teve como objetivo verificar aspectos reprodutivos de *Rhizoprionodon porosus* (Poey, 1861) capturados em pescarias de pequena escala em águas costeiras do Nordeste do Brasil. As amostras foram obtidas durante as estações seca e chuvosa entre 2015 e 2016. As amostras foram sexadas, medidas (cm ± d.p.), pesadas (g ± d.p.), evisceradas e tiveram seus estágios de maturação verificados. Foram amostrados 169 (103 machos e 66 fêmeas) entre 4 e 30 m de profundidade. Foram confirmados três estádios de maturação: neonatos (37,95 ± 3,59 cm comprimento total (Lt); 230,02 ± 72,90g peso eviscerado (We), juvenis (47,10 ± 2,91 cm Lt; 436,7 ± 79,60g We) e adultos (69,15 ± 12,29 cm Lt; 1556,08 ± 831,40g We). O coeficiente alométrico negativo para adultos sugere uma estratégia de adaptação para atingir tamanhos maiores mais rapidamente, evitando a predação. O tamanho para a primeira maturação sexual foi estimado em 57,5 cm. No entanto, mais de 60% do total de amostras correspondeu a neonatos. O período de reprodução parece ocorrer continuamente com as fêmeas migrando para águas rasas para dar à luz durante a estação seca. A abundância de neonatos e algumas fêmeas nos estágios tardios da maturidade indica que a pesca está ocorrendo em áreas de berçário, o que pode afetar o recrutamento de novos indivíduos no estoque populacional.

Palavras-chave: migração tubarão costeiro, tamanho de maturação sexual, áreas de berçário.

Introduction

Elasmobranch species belonging to the Carchahinidae family comprises small to large sized sharks, mostly in marine tropical and subtropical waters (CARPENTER, 2002; YOKOTA; LESSA, 2006). There are about twelve known genera, among them, the genus *Rhizoprionodon*, which corresponds to small sharks found within coastal shallow waters. From the seven known species, only *Rhizoprionodon lalandii* (Müller & Henle, 1839) and *R. porosus* (Poey, 1861) are found in the Brazilian coast (LESSA et al., 2008; MATOS et al., 2001) and together, they represent between 50 to 60% of total coastal sharks caught by the artisanal fisheries along the Brazilian coast (MOTTA et al., 2005).

The Caribbean sharpnose shark *R. porosus*, occurs in shallow waters (usually within 100 m depth) along the western Atlantic Coast, from Honduras, in Central America, to South of Uruguay, in South America (COMPAGNO, 1984b; ROSA; GADIG, 2014). The species has a socioeconomic importance as it is regionally commercialized its fresh, salted and frozen meat, besides some byproducts such as skin, cartilage and liver oil (CARPENTER, 2002). In Brazil, *R. porosus* is mainly caught as a by-catch from high value target species fisheries and despite being one of the most abundant coastal shark species in Brazil (MATTOS et al., 2001), fisheries and degradation on inshore habitats imposes the main threats to the species along their geographical distribution (MENDONÇA et al., 2011; YOKOTA; LESSA, 2006).

Rhizoprionodon porosus is a placental viviparous species (COMPAGNO, 1984a), producing 1 to 6 pups in an estimated pregnancy of 10-11 months (MATTOS et al., 2001), making it particularly susceptible to overfishing (YOKOTA; LESSA, 2006). Such susceptibility is even more aggravated due to its dependency of coastal zones for nursery purposes, which are under intense fisheries activities (MACHADO; SILVA; CASTRO, 2001).

The comprehension on basic aspects such as population structure and reproductive period allows better understanding of conservation status and therefore the development of management plans for the species. Despite the relevance, few studies on reproductive aspects have been reported to Northeast Brazil (MATTOS et al., 2001; ROSA; GADIG, 2014). In this context, the present study aimed to describe the reproductive aspects of *R. porosus* caught by artisanal fisheries in coastal waters of Rio Grande do Norte, Northeast of Brazil.

Material and Methods

Specimens were obtained monthly from September, 2015 to August, 2016 along 20km stretch in the coastal waters (from 3 to 30m depth) of the state of Rio Grande do Norte (Figure 1) with the assistance of local small-scale fishers who used bottom gillnets (mesh size of 40 and 50 mm) on motor boats ranging from 7 to 10 m length. The sampling was authorized under the following license number: 095/2016 – Process number: 23082.025801/

2015 by the Comissão de Ética no Uso de Animais (CEUA) – Universidade Federal Rural de Pernambuco.

The species identification was conducted according to (FAO, 2016; GOMES et al., 2010). Each specimen was numbered, weighted (g ± s.d.) and measured (cm± s.d.) with precision up to two decimal places. The sex and maturity stages were analyzed considering the regional seasonality, assuming by rainy season the period from March to August; and dry season from September to February for the state of Rio Grande do Norte, Northeastern coast of Brazil (RAO et al., 2016).

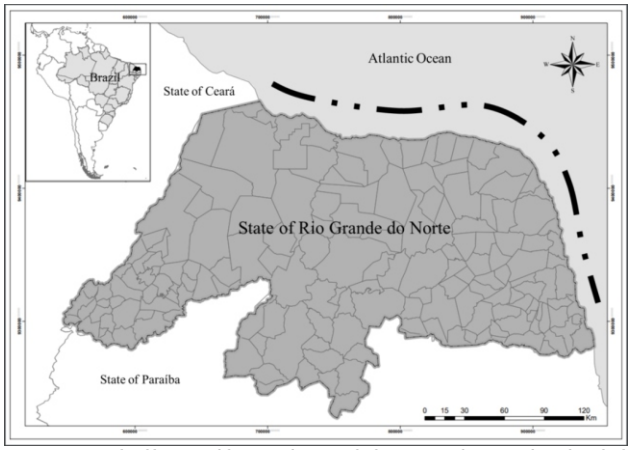

Figure 1. Geographical location of the state of Rio Grande do Norte, Northeastern of Brazil. Dashed line on the coast represents the sampling zone. Elaboration: Carvalho, M. M. Source: OBS, 2019.

Sampling structure, maturity stage and sex ratio

The sampling structure range for total length (Lt) and total eviscerated weight (We) were verified and discriminated on a bean plot chart. Sex and maturity stages identification for both sexes follows (MACHADO; SILVA; CASTRO, 2001). In addition, clasper size and its flexibility were used as complementary information to support previous sex and maturity stages determination for males (MATTOS et al., 2001; MOTTA et al., 2007). Sex ratio was calculated considering the relative frequency of males and females by dry and rainy season; and by maturity stages. Kruskal-Wallis (W), Mann-Whitney (U) and Chi-square (χ^2) tests were performed assuming significant difference at $p<0.05$.

Length-weight relationship

The length-weight relationships were calculated considering total length Lt (cm) and eviscerated weight We (g) values for neonates, juveniles, adults and general (grouped data) in plotted in chart, adjusting the fitting curves to potential equation type: $We= a.Lt^b$, where "a" is the intercept; and "b" the allometric coefficient of growth (b=3 isometric; b<3 allometric negative; and b>3 allometric positive) (HOFFMAYER et al., 2013; MATTOS; PEREIRA, 2002).

Size at first maturity (L_{50})

The first maturity of the species was determined by the relative frequency distribution of maturing and mature individuals in Lt classes (HOFFMAYER et al., 2013; MATTOS; PEREIRA, 2002). For this calculation, immature individuals were not included in the analysis. The curve was then adjusted to logistic type according to (CORRO-ESPINOSA; MÁRQUEZ-FARÍAS; MUHLIA-MELO, 2011).

Gonadossomatic Index (GSI) and period of reproduction

The Gonadossomatic Index was calculated by the percentage relation: GSI= (Gonad weight/ eviscerated weight) * 100. The Kruskal-Wallis (W) and Mann-Whitney (U) tests were performed in order to compare GSI values among the maturity stages and also between the rainy and dry seasons. The period of reproduction was inferred based on the medians of maturity stages by the seasonality (HOFFMAYER et al., 2013; MOTTA et al., 2007).

Results

Sampling structure, maturity stage and sex ratio

A total of 169 *R. porosus* sharks was sampled (103 males and 66 females). The total length (Lt) ranged from 32.7 to 85.5 cm (mean 46.72 ± 13.47) for males and from 24 to 91 cm (mean 45.46 ± 14.82) for females. Whereas for the eviscerated weight (We) it was recorded a variation from 90.5 g to 3103 g (mean 550.11 ± 627.04) for males and from 102 to 3183 g (mean 547.74 ± 703.67) for females. There were no significant differences for Lt (t test= 0.5701; p= 0.5696; d. f. =167) and We (t test= 0.0228; p= 0.9818; d.f. =167) between sexes. The overall sex ratio differed from the expected 1:1 (d.f.= 1; $p<0.05$) with predominance of male by 1.30 M: 1F (χ^2=17.967) and 1.67 M: 1F (χ^2=28.914) for the rainy and dry seasons, respectively.

In this study it was verified three maturity stages for *R. porosus*: 1) *neonates*– immature individuals (37.95 ± 3.59 cm Lt; 230.02 ± 72.90g We) with prominent umbilical scars; filiform and transparent gonads, males with short and flexible clasper; 2) *juveniles*– maturing individuals (47.10± 2.91 cm Lt; 436.7 ±79.60g We) with no umbilical scars; enlarged, reddish and vascularized gonads, males with elongated and semi-rigid clasper; and 3) *adults*– mature individuals (69.15 ± 12.29 cm Lt; 1556.08 ± 831.40g We) with enlarged vascularized gonads (female occasionally presenting oocytes; and males presenting large, rigid clasper). There was a high predominance of neonates sampled in this study (61% from the total). In general, neonates, juveniles and adults presented significant demarked Lt and We range (W_{size} = 132.8; p= 4.389E-23; W_{weight} = 111.4; p= 2.811E-19), moreover Mann-Whitney tests indicated both Lt and We ranges differed among sex and seasons (Full Figure 2).

When considering the regional seasonality, there was a general predominance in captures of neonates (73.17%) during the dry season (September to February) (χ^2= 36.082; d.f.= 2; p=1.4621E-08). Total length and eviscerated weight distribution indicated males were slightly larger and heavier than females at neonate and juvenile stages, whereas most of female adults had larger length and weight range at both dry and rainy seasons. For maturity stages the sex ratio differed from the expected by 1.51 M: 1F for neonates (χ^2= 46.487); 1.5 M: 1F for juveniles (χ^2= 12.949); and 1.77M: 1F for adults (χ^2= 9.1144) (χ^2 test for each; d.f.= 1; $p<0.05$).

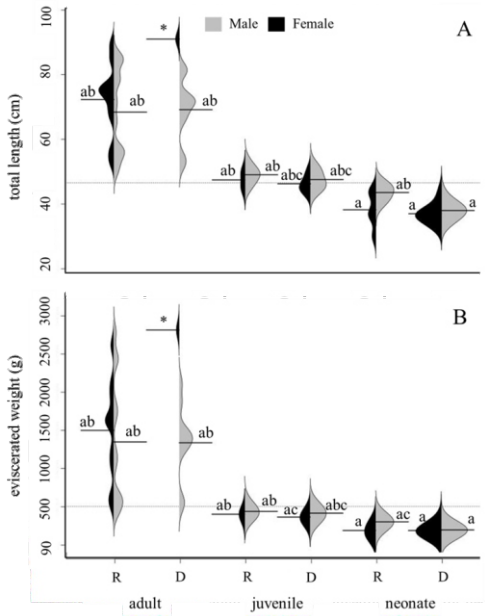

Figure 2. Sampling distribution for **A.** Total length (cm) and **B.** Eviscerated weight (g) of adults (n= M:23; F:13), juveniles (n= M:18; F:12) and neonates (n= M:62; F:41) of *Rhizoprionodon porosus* caught by small-scale fisheries from the state of Rio Grande do Norte, Northeastern of Brazil. R- rainy (March to August) and D-dry season (September to February). Different letters represent significant differences (paired-wise comparisons by Mann-Whitneytest, $p < 0.05$).*data deficient (n<5).

The capture of neonates, juveniles and adults of *R. porosus* along the year presented a pattern of stratification by water depth. During the dry season (September to February) neonates were captured predominantly in shallow waters within 10m depth, whereas individuals at older maturity stages were found between15 and 30m water depth, exception for some female adults sampled within 4m. Despite fewer samplings (46 individuals in total), a similar stratification pattern between maturity stages and water depth was observed during the rainy season (March to August) (Figure 3A).

Based on the frequencies of capture, adults may migrate from deep to shallow waters for giving birth at the end of dry season, returning afterwards. As the neonates increase in size and maturate they tend to migrate to deeper waters, where they reach sexual maturity. After copulation and gestation of one year round, female adults return to shallow waters for giving birth, which renews the species life-history inshore the state of Rio Grande do Norte (Figure 3B).

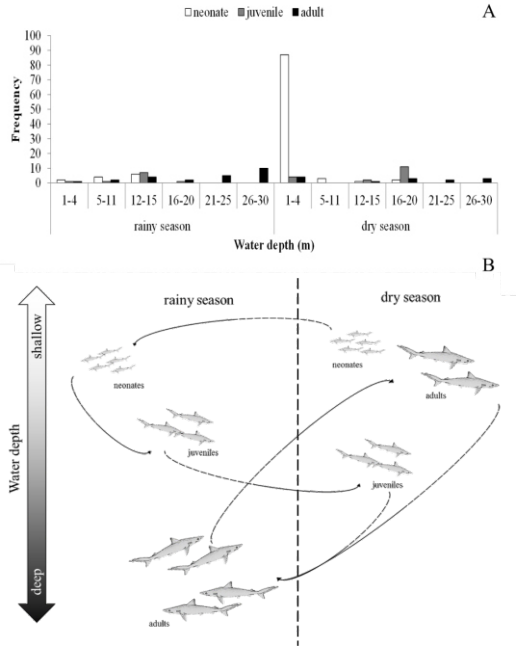

Figure 3. A. sampling frequency by water depth (m) and B. estimated migration of *R. porosus* (neonates, juveniles and adults) captured by small-scale fisheries from the state of Rio Grande do Norte, Northeastern of Brazil at dry (September to February) and rainy (March to August) seasons.

Length-weight relationship and size at first maturity

From the generated equations, adults presented negative allometric growth coefficient (b<3), indicating *R. porosus* at this maturity stage gets larger by length than weight. Neonates and juveniles, however, presented isometric coefficients (b~3), translated by a proportional growth by length and weight at those stages of development. The overall equation for the species regardless its maturity stages presented an isometric growth (Figure 4). The size of maturity estimated for juveniles and adults of *R. porosus* regardless the sex ranged from 43.7 to 91 cm Lt, with 50% of the individuals reaching maturity at 57.5 cm Lt.

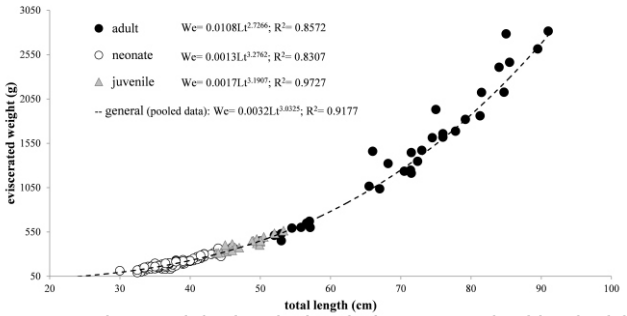

Figure 4. Growth estimative by length-weight relationship for neonates, juveniles, adults and pooled data (n= neonates: 100; juveniles: 30; adults: 36) of *R. porosus* caught by small-scale fisheries from the state of Rio Grande do Norte, Northeastern of Brazil.

Gonadossomatic Index (GSI) and period of reproduction

The Gonadossomatic index range differed between neonates, juveniles and adults (W= 37.88; p=3.987E-07), confirming distinct gonadal development among maturity stages (Figure 5). Although the highest GSI value during the rainy season (4.92) may suggest a reproductive peak, the Mann-Whitney test failed to detect significant differences for GSI values between rainy and dry season for each maturity stage: neonates (U=129; p =0.0546), juveniles (U=28; p =0.8708) and adults (U=83; p =0.2739). Therefore, considering the maturity stages overlap and higher GSI values for neonates, juveniles and adults at both seasons, these results indicate the reproduction of *R. porosus* occurs along the year.

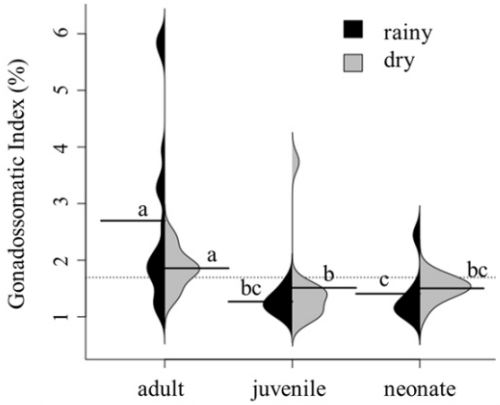

Figure 5. Gonadossomatic Index (%) distribution for neonate, juvenile and adults of *R. porosus* captured by small-scale fisheries from the state of Rio Grande do Norte, Northeastern of Brazil, at rainy and dry seasons. Different letters represent significant differences among maturity stages (Kruskal-Wallis; paired-wise comparisons by Mann-Whitney test; p < 0.05).

Discussion

Studies targeting the genus *Rhizoprionodon* have evidenced females present size and weight ranges greater than those from males (MOTA et al., 2007; SEN et al., 2018; TAYLOR; HARRY; BENNETT, 2016).. In the Northeastern of Brazil, the same trend has been registered for *R. porosus*, presenting females significantly larger than males by size and weight (MATTOS et al., 2001). The current study, the ranges were lower (24.0-90.5 cm Lt and 90.5-3183g We) and similar to both sexes. This variation may have resulted from fishing gear selectivity, mainly caught by bottom gillnets at 15 m depth. Adults accounted for 21% of total sampling, which is still considered consistent to the species population standards (YOKOTA; LESSA, 2006).

Sex ratio of *Rhizoprionodon* species may fluctuate by their geographic distribution and seasonality. On the Southeastern coast of Brazil, sex ratio for *R. lalandii* has been reported as proportional (MACEDO; SOUSA; BATISTA, 2012; MOTTA et al., 2007). Although, partial predominance has also been reported for males from April to July (rainy season) and females during November, middle of dry season (MOTTA et al., 2005). On the Northeastern coast, *R. porosus* females were more abundant throughout the year but immature and maturing males (33-70 cm Lt) were predominant in comparison to females at the same size range, suggesting sexual segregation by size (MATTOS et al., 2001). In this study, *R. porosus* sex ratios were male-biased during rainy and dry seasons for all sampling size range. From this result it is considerable to suppose either males might be abundant in the stock or sampling restriction by fishing gear selectivity.

Coastal zones play important roles on the life-history of shark species. On the coast of the state of Rio Grande do Norte at least four shark species, including *R. porosus,* use inshore waters as nursery areas during their first developmental stages (YOKOTA; LESSA, 2006). In this study, neonates were captured in shallow waters throughout the year (mostly during the dry season) and accounted for over 60% of total sampling. Such scenario may affect the populations by decreasing the recruitment. Maturing and mature individuals were also sampled within 5m depth, the majo-

rity however over 15m depth. This may suggest the species migrates to deep waters as it matures, returning at the end of dry season (around first maturity size) for giving birth. A similar pattern of migration has been observed for *R. lalandii* on the Southeastern coast of Brazil (MOTTA et al., 2005).

The length-weight relationship for *Rhizoprionodon* species may vary between sexes and environmental conditions. On the northeastern coast of Brazil, it was verified isometric growth to *R. porosus* for both sexes (MATTOS et al., 2001) and also negative and positive allometric growth for males and females, respectively (MATTOS; PEREIRA, 2002). In this study, despite neonates and juveniles followed an isometric growth trend, adults expressed a negative allometric growth. These results suggest the species tends to grow faster by size at late juvenile stage, requiring suitable environmental conditions to reach maturity. Fast-growing patterns for *Rhizoprionodon* have been inferred as a life-history strategy to avoid predation by larger shark species in nurseries zones (CARLSON et al., 2008; YOKOTA; LESSA, 2006). Therefore *R. porosus'* life-history inshore the state of Rio Grande do Norte may be strictly dependent on nursery environmental conditions.

The sizes at first maturity (L_{50}) for *Rhizoprionodon* sharks seem to be affected by the species latitude distribution along the Brazilian coast. The L_{50} for *R. lalandii* has been estimated at 55 cm Lt on the Northern (LESSA; SANTANA; ALMEIRA, 2009), 65 cm Lt on the Northeastern (MACEDO; SOUSA; BATISTA, 2012) and 62 cm Lt on the Southeastern coast of Brazil (MOTTA et al., 2007). Assuming water temperature at different latitudes may affect L_{50} in sharks (LOMBARDI-CARLSON et al., 2003), it seems there is a trend to reach sexual maturity by smaller sizes at warmer coast zones in Brazil (North coast ~ 27-30°C; Southeastern coast ~ 15-18°C).

Despite the similar range of temperature between Northern and Northeastern coast (~ 25-35°C), in this study, the L_{50} estimated was 57.5 cm Lt, smaller than ~65 cm Lt previously verified to *R. porosus* within that range (MACHADO; SILVA; CASTRO, 2001; MATTOS et al., 2001). Thus, it is reasonable to account some alternatives (e.g.: fishing gear selectivity, oceanographic conditions, etc.) which are contributing to early sexual maturity for *R. porosus*. Further studies may be necessary.

The reproductive period for *Rhizoprionodon porosus* has been marked by high values of GSI due to the abundance of late mature adults generally before the rainy period on the Western South Atlantic coast. From Colombian to the Northeastern Brazilian coast, high values of GSI have been verified anticipating the rainy season for *R. porosus* (DALLOS; ÁLVAREZ; P., 2012; MACHADO; SILVA; CASTRO, 2001; MATTOS et al., 2001). During the rainy season, availability of nutrients increase in nursery areas at tropical zones, therefore, sharks tend approximate for optimizing reproduction and offspring survival (YOKOTA; LESSA, 2006). In this study, the highest GSI values were prominent for adults at both seasons, indicating *R. porosus* reproduces throughout the year. Moreover, the predominance of neonates during the dry season suggests females return for giving birth before rainy season, corroborating with previous patterns observed for the species on the Northeastern coast of Brazil (MATTOS et al., 2001).

Conclusion

This work have provided fundamental information concerning current population structure and reproductive aspects of *R. porosus* captured by small-scale fisheries from the state of Rio Grande do Norte, Northeastern of Brazil. Despite the indications of a constant reproductive period throughout the year, the high abundance of neonates captured at nursery zones reflects the main area of fisheries operation and therefore, may affect the species life-history by decreasing juveniles recruitment in the population.

Acknowledgements

The authors thank all the fishers who collaborated generously providing the specimens during the fieldwork. Special thanks to the fishers Arnaldo and Wanezia for the fieldwork support. The authors are also thankful to CAPES (Coordination for the Improvement of Higher Education Personnel) which funded this study by a Master's Degree grant to MMC (Ciências do Mar II- Program Announcement: 43/2013).

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