

THE USE OF ACOUSTIC TELEMETRY TO MONITOR FISH SPECIES IN MARINE PROTECTED AREAS: A SYSTEMATIC REVIEW WITH NOTES ON BRAZILIAN PERSPECTIVES

Uso da telemetria acústica no monitoramento de peixes em áreas marinhas protegidas: uma revisão sistemática com notas sobre as perspectivas brasileiras

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ABSTRACT

Inferring pathways used by organisms within ecosystems is essential to the design, management and evaluation of Marine Protected Areas (MPAs). This study aimed to present a systematic review on the literature regarding the use of acoustic telemetry to monitor marine fish movement and its application on MPAs. Searches were conducted on electronic databases. The first studies using telemetry on marine fish date back to the 60's, while application on MPAs only appeared 30 years later. However, over the last decade, studies in MPAs accounted for 20% of the overall acoustic telemetry publications on marine fish species. Recent technological development has had an important impact on those results. The number of studies inside MPAs followed the number of general studies and coverage areas of MPAs declared around the world, although frequency of studies did not match MPA coverage in some countries. Developed countries scored more studies, probably due to the relative high cost of acoustic telemetry. Studies in Brazilian MPAs are scarce, with only one study available on elasmobranchs. Brazil has recently increased its MPA coverage to 26%, so it is expected to increase the need for MPA effectiveness studies. Brazilian participation on global tracking networks may help filling this gap.

Keywords: PRISMA statement, fish movement, remote monitoring, MPA effectiveness, tracking networks.

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RESUMO

O estudo da movimentação animal nos ecossistemas é uma importante ferramenta para a criação, o manejo e a avaliação de Áreas Marinhas Protegidas (AMPs). Este trabalho objetivou apresentar uma revisão bibliográfica sistemática na literatura científica abordando o uso de telemetria acústica para monitorar a movimentação de peixes e sua aplicação em AMPs. Para isso, foram realizadas pesquisas em bases de dados eletrônicas. Os primeiros estudos usando telemetria acústica em peixes datam da década de 1960, porém essa técnica só foi aplicada em AMPs 30 anos depois. Na última década, estudos em AMPs representaram 20% do total de publicações com telemetria acústica com peixes em ambientes marinhos. O desenvolvimento tecnológico recente teve um importante impacto nesses resultados. O aumento no número de estudos realizados em AMPs foi congruente com o crescente número de estudos gerais de telemetria e com o aumento em áreas declaradas como AMPs globalmente. No entanto, não foi observada relação entre a frequência de estudos e a cobertura de AMP em alguns países. Países desenvolvidos produziram mais estudos, provavelmente devido ao alto custo da telemetria acústica. Estudos no Brasil foram escassos, com apenas um em elasmobrânquios. Recentemente, o Brasil elevou sua cobertura marinha protegida para 26%, portanto, espera-se que isso impulse estudos avaliando a efetividade de AMPs e que a participação brasileira em redes globais de telemetria ajude a preencher essa lacuna.

Palavras-chave: protocolo PRISMA, movimento de peixes, sensoriamento remoto, efetividade de AMPs, redes de telemetria.

INTRODUCTION

Movement is a key factor that shapes several aspects of fish behavior such as habitat use, home range size, reproduction and diel and seasonal activity patterns (e.g. Marshall *et al.*, 2011; Lee *et al.*, 2015; Di Lorenzo; Claudet & Guidetti, 2016; Gandra; Erzini & Abecasis, 2018) and therefore, influences the dynamics, structure and distribution patterns of fish populations. Telemetry, *i.e.* the remote measurement of biological variables, is a technology that allows gathering information on the biology and behaviour of the animals, including movement tracking, one of the most important preconditions for management decisions (Spedicato; Carbonara & Lembo, 2005). It involves placing electronic devices (“transmitters” or “tags”) on animals that auto-nomously transmit data to data logging or relay-receiving stations (Hussey *et al.*, 2015).

One important driver behind growth in marine animal tracking studies has been the need for distribution and movement data to inform conservation policy and management (Hays *et al.*, 2019). Marine Protected Areas (MPAs) are spatially delimited areas of the marine environment that are established for general conservation reasons, but expectations often include increased fishery catches in adjacent areas (Edgar; Russ & Babcock, 2007). In 2010, the Convention on Biological Diversity (CBD), adopted the Strategic Plan for Biodiversity 2011-2020, which includes Aichi Biodiversity Targets. Aichi Target 11 called for 10% of coastal and marine areas to be conserved by 2020 through effectively managed, ecologically representative and well-connected systems of protected areas, and integrated into the wider landscapes and seascapes (SCBD, 2010). Thus, one important field of study to assess those attributes is the remote monitoring of marine organisms, including fish.

The present study aimed to present a systematic review on the scientific literature concerning the use of acoustic telemetry to monitor fish movement and its application on

the design and assessment of MPAs, discussing the global expansion and recent advancements of the method. Brazil has just reached the mark of 20% of its Exclusive Economic Zone (EEZ) under a designated MPA (Soares & Lucas, 2018), therefore the use of acoustic telemetry as a tool in Brazilian MPAs is also discussed as well as the role of global and regional collaborative tracking networks.

MATERIALS AND METHODS

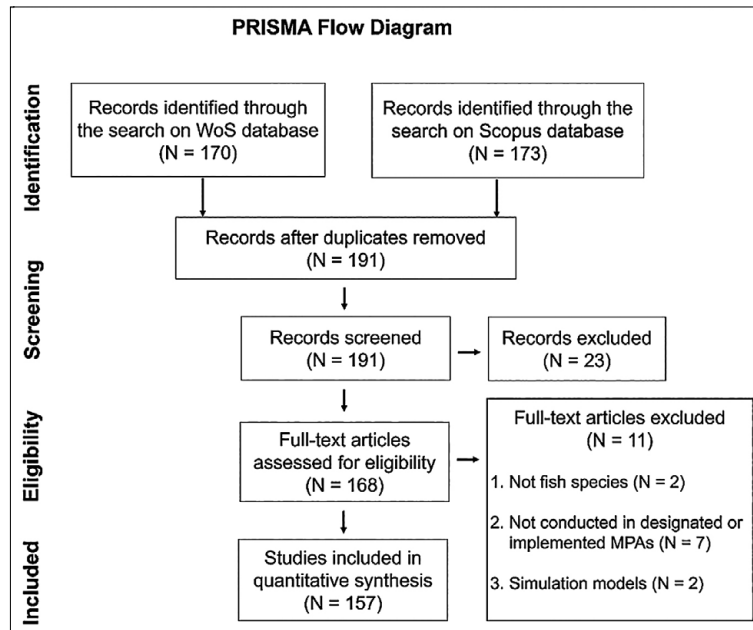
In October 2020, two searches were conducted on electronic databases (Web of Science and SCOPUS) to identify the up-to-date relevant scientific literature on the use of acoustic telemetry to monitor fish species in marine or estuarine environments (Search 1) and specifically in marine protected areas (Search 2). Searches were conducted on the fields Title, Abstract and Author's keywords, and only articles published in English language were selected. The terms used on both searches are presented in Table I.

Search 1 returned a total of 1,203 publications after removals of duplicates. The article's titles, abstracts and keywords were then screened, and 897 studies remained for analysis. For the Search 2, the systematic review followed the steps defined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher *et al.*, 2009) (Figure 1). Articles were filtered for the quantitative analysis based on the following exclusion criteria: the study (I) addressed species other than fish (e.g. cuttlefish), (II) were not conducted in already implemented or designated (with well-established borders) marine protected areas and (III) evaluated MPA effectiveness based on simulation models. For each eligible article (N = 157) the following data were compiled: year of publication, study location (country or territory), main objective, habitat type, species, number of tagged fish, overall duration of the study, application of other field methods (e.g. satellite tracking, mark-recapture) and partnership with tracking networks. Additionally, information on the size of implemented or designated MPAs for the countries listed in the articles were obtained from the Marine Protection Atlas website (MPAtlas.org, 2020).

Table I - Combination of terms used on the two searches performed on the Web of Science and Scopus databases. Searches were conducted on Title, Abstract and Author's keywords fields

<p>Search 1: acoustic telemetry on fish species in marine and estuarine environments</p> <p>(acoustic OR ultrasonic OR sonic)</p> <p>AND</p> <p>(telemetry OR tracking OR tagging)</p> <p>AND</p> <p>(fish OR fishes OR shark* OR ray* OR elasmobranch* OR salmon* OR trout* OR eel* OR grouper* OR cod* OR catfish* OR bass)</p> <p>NOT</p> <p>(freshwater OR river* OR lake* OR dam* OR stream* OR hydroelectric* OR reservoir*)</p>
<p>Search 2: acoustic telemetry on fish species in marine protected areas</p> <p>(acoustic OR ultrasonic OR sonic)</p> <p>AND</p> <p>(telemetry OR tracking OR tagging)</p> <p>AND</p> <p>(fish OR fishes OR shark* OR ray* OR elasmobranch* OR salmon* OR trout* OR eel* OR grouper* OR cod* OR catfish* OR bass)</p> <p>AND</p> <p>mpa OR marine protected area* OR marine reserve* OR marine park* OR marine sanctuary</p>

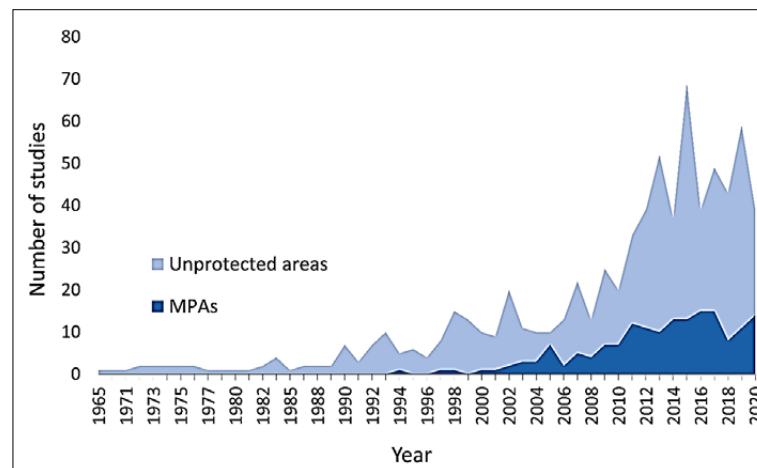
Figure 1 – PRISMA flow diagram for systematic review, including sample sizes and exclusion criteria



RESULTS

Studies using acoustic telemetry on fish species in marine or estuarine environments (Search 1, n = 897) were first published in the 1960's. The number of studies remained relatively low for the following decades (1965-1989) (Figure 2) with an average of less than 2 publications per year. During the 1990's, the number of publications increased fourfold (8 publications/year) and has been growing exponentially over the last decades: 2000-2009 (18 publications/year) and 2010-2020 (55 publications/year).

Figure 2 – Increase in the number of acoustic telemetry studies conducted on fish species in marine and estuarine environments (Search 1, light blue) and specifically in marine protected areas (MPAs) (Search 2, dark blue) since 1965



Studies reporting the use of acoustic telemetry to monitor fish species inside MPAs (Search 2, n = 157) were first published in the 1990's (Figure 2). Since then, the number of

publications has increased from 3.4 per year (2000-2009) to 11 publications per year (2010-2020). All the results presented hereafter refer exclusively to the publications yielded by the second search, that is, the ones related to MPAs.

The found MPAs were located in 36 countries and territories. Three countries were responsible for 55% of the studies: United States of America (national waters and overseas territories; 28.5%, N = 45), Australia (19%, N = 29) and Portugal (7.5%, N = 12), whereas two-thirds of the countries published only one or two studies (Figure 3). There was no correspondence between the percentage of MPAs (relative to the area of the EEZ of each country) and number of studies. While countries with low percentage of MPAs (*e.g.* Portugal, Italy and Spain) have a relatively high number of publications, other countries such as Brazil, Mexico and France have low numbers of studies despite the high percentage of their EEZ designated as MPAs.

Regarding the type of habitat covered by the MPAs, the majority of studies were conducted on coral or rocky reef habitats (73.2%, N = 115), followed by fewer studies (10.2%) on unconsolidated substrate areas (*e.g.*, seagrass or macroalgae beds, sand/mud bays and estuaries), mixed habitats (10.2%) (*i.e.*, mostly coral/rocky reefs associated to seagrass, sand or mangroves), open ocean, submerged banks or seamounts (3.8%) and fjords or sounds (2.6%). A total of 140 fish species (31 chondrichthyan and 109 teleost species) were acoustically monitored inside MPAs. The most studied families in terms of both number of studies and species were: Epinephelidae (28 studies and 17 spp.), Carcharhinidae (25 studies and 12 spp.), Sparidae (21 studies and 10 spp.), Lutjanidae (19 studies and 13 spp.) and Labridae (17 studies and 15 spp.). Many species (20%) are under some level of threat, according to the criteria adopted by the international Union for conservation of Nature's Red List of Threatened Species - IUCN red list (Critically Endangered = 3 spp., Endangered = 3 spp. or Vulnerable = 22 spp.), whereas some others are classified as Near Threatened (11.5%, 16 spp.), Least concern (57.8%, 81 spp.), Data Deficient (5.7%, 8 spp.) and Not Evaluated (5%, 7 spp.).

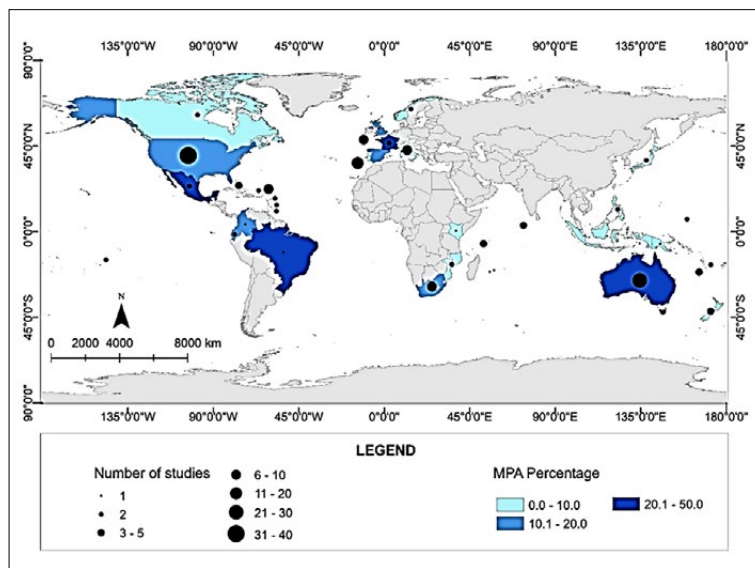


Figure 3 - Global map showing the locations (countries or territories) where the studies using acoustic telemetry on fish species were conducted in marine protected areas (MPAs). Shades of blue (light blue to dark blue) indicate the percentage of each country's Exclusive Economic Zone Covered by MPAs*. The number of studies is proportional to the black circle's size. Data source information: Coordinate System GCS WGS 1984; units: Degrees; datum: WGS 1984

* Three territories (not distinguishable on the map) had more than 50% of their EEZ covered by MPAs: Martinique (99.7%), Chagos Archipelago (98.02%), and New Caledonia (94.25%).

Acoustic telemetry has been mainly used as a tool to evaluate the protection effectiveness afforded by the MPAs to fish populations (55.4%, N = 87) as well as to investigate spatial and temporal aspects of fish behavior (38.2%, N = 60). The majority of studies were performed in (or included) no-take zones (112 out of 157). Fewer studies (3.8%) focused on the assessment of specific human impacts (e.g. feeding activity and fishing mortality), on the development of analytical methods (2%), and tag retention time (0.6%). In most cases, studies were conducted on a single species at a time (76.4%, N = 120), with less studies tagging simultaneously two (10.2%), three (3.8%) or four or more species (9.6%). Although less numerous, the number of studies with a multi-specific approach has increased over the past decade (Figure 4-A). A recent increase in the number of tagged individuals per study (Figure 4-B) and in the overall duration of the studies (Figure 4-C) was also observed.

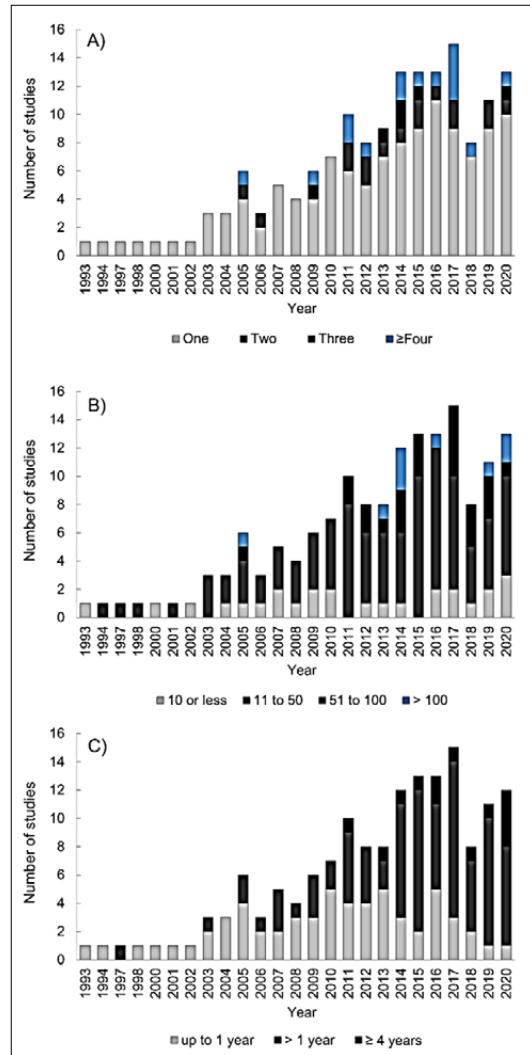
Among the studies analyzed, 18 (11.5%) were part of a regional or global tracking network: the Integrated Marine Observatory System (IMOS) in Australia (n = 13), the Acoustic Tracking Array Platform (ATAP) in South Africa (n = 2), the Ocean Tracking Network FACT node (Florida Atlantic Coast Telemetry Network) (n = 2) and the US Caribbean Acoustic Network USCAN (n = 1).

DISCUSSION

The onset of studies in acoustic telemetry on fish species in marine or estuarine environments was in the 1960's (Bass & Rascovich, 1965). In subsequent decades, the number of studies remained low, experiencing an accelerated growth in the two last decades. Indeed, in recent decades, technological developments in miniaturization (March *et al.*, 2011), battery engineering and hard and software development have enabled this development and the monitoring of aquatic organisms in a multitude of environments (Hussey *et al.*, 2015).

However, studies using acoustic telemetry inside marine protected areas (MPAs) only started three decades later, in the 1990's (Holland *et al.*, 1993), following the increase in the coverage area by MPAs declared worldwide (Worm, 2017; O'Leary *et al.*, 2018).

Figure 4 - Number of published acoustic telemetry studies per year in relation to the: (A) number of tagged species, (B) number of tagged individuals and (C) duration of the studies



During the last decade, studies in MPAs accounted for 20% of the total number of published studies using fish acoustic telemetry in marine or estuarine environments.

The geographic distribution of those studies, however, was uneven. Although studies in MPAs were distributed across several countries and territories, three developed countries (United States of America, Australia, and Portugal) concentrated 55% of the studies. The high number of studies in MPAs did not match the relative total area of MPAs of those countries either, as the three added covered only 28.4% of MPA area in the world: US (13.9%), Australia (14.2%) and Portugal (0.3%) (MPAtlas.org, 2020). Indeed, countries with lower MPA areas (*e.g.* Portugal, Italy and Spain) had a higher number of studies in their MPAs in comparison with developing countries such as Brazil and Mexico, that showed a low number of studies despite the high percentage of their EEZ designated as MPAs. This difference is possibly related to the relative high cost of those studies, that even with technological improvements, remain expensive and limited to few manufactures located in developed countries (Garcia *et al.*, 2014; Hellström *et al.*, 2016).

It was observed that the main objective of the studies conducted on MPAs was to evaluate the protection effectiveness afforded to fish populations and most of them were performed in (or included) no-take zones. A high percentage of studies were concentrated on coral or rocky reef habitats, probably as those habitats typically harbor more territorial species (Sale, 2002; Burger & Gochfeld, 2001), thus allowing for most cost-effective designs, and have shown positive effects deriving from MPA establishment (Steneck *et al.*, 2018). Accordingly, the majority of studied families of bony fish in terms of both number of studies and species, were reef associated (*e.g.* groupers, snappers, and parrotfishes) (La Mesa *et al.*, 2012; Garcia *et al.*, 2014; Kendall *et al.*, 2017). In addition, 20% of the species were under some level of threat according to IUCN Red List criteria, indicating that those status make studies even more necessary (Afonso; Fontes & Santos, 2011; Daly *et al.*, 2020).

Another interesting finding was the increase, in the last decade, of the number of studies with a multi-specific approach. This application is especially important for studies dealing with the design and spatial effectiveness of MPAs. Data from acoustic telemetry show the overlap in the spatial occupation of prey and predator species, aggregations and movement of threatened species, essential information for marine spatial planning (Hussey *et al.*, 2015). Another finding was the increase in the duration of the tracking period, also derived from technology improvement, and allowing for studies to encompass a significant period of life of individuals (Pittman *et al.*, 2014).

In the last decade there was also an increase in the establishment of acoustic tracking networks, with the first study on MPAs, as part of a network, published in 2011 (Field *et al.* 2011). Since then, 18 studies were published as a result of regional or international partnerships. Two countries that concentrated the higher number of studies, US and Australia, also concentrated the networks cited. In Brazil, in spite of the still low number of published studies to date, a tracking network was created as part of the Ocean Tracking Network OTN, a Canadian based initiative that aims to form a global partnership that documents the movement and survival of aquatic animals to both understand how these populations are being influenced by changing environmental conditions and to support their sustainable management (Iverson *et al.*, 2019).

Indeed, Brazil in spite of the higher percentage of MPAs (26% of EEZ, although only 3.3% are considered fully or highly protected) (Soares & Lucas, 2018) had only one study applying fish acoustic telemetry inside a MPA identified in the Search 2, out of the five

studies detected for Brazil in Search 1. The study assessed the activity patterns of sharks inside the Marine Park of Fernando de Noronha (Garla; Gadig & Garrone-Neto, 2017). In addition, another study on rays on the Saint Peter and Saint Paul Archipelago was identified (Mendonça *et al.*, 2018). However, at the time of the study, the area had not yet been declared a protected area, and no mention was made to MPA in the study, so it was not added to the survey. It is worth mentioning that since 2018 the region has become a MPA (Soares & Lucas, 2018). Also, two other acoustic telemetry studies conducted on elasmobranchs species inside Brazilian MPAs (Garla *et al.*, 2006; Wetherbee; Gruber & Rosa, 2007) were not identified on both searches as the surveyed terms (*i.e.*, acoustic* OR sonic* OR ultrasonic*) were not mentioned on the articles' researched fields (title, abstract and author's keywords).

In Brazil, effectiveness of MPAs in terms of increase in the abundance and biomass of fish inside its boundaries has been relatively well documented (Floeter; Halpern & Ferreira, 2006; Prates *et al.*, 2007; Anderson *et al.*, 2014), but reports on benefits through spillover to adjacent areas and effectiveness in terms of biodiversity protection and fisheries benefits are scarce. Also, connectivity of Brazilian MPAs through larval dispersion has been discussed (Endo *et al.*, 2019), as well as its implication on the design of a representative MPA system (Magris *et al.*, 2020).

The present study has shown that acoustic telemetry, as an effective technique to study fish movement, has been applied in the assessment of MPAs worldwide. In spite of comparatively high costs in relation to other techniques (*e.g.* UVC, mark-recapture and larval dispersal modelling) the results are unique and can also show direct benefits for adjacent areas (Reyier *et al.*, 2020). Moreover, considering the impacts in marine habitats caused by human actions, including climate change, acoustic telemetry arises as an important tool in inferring and predicting how organisms and communities rearrange themselves when faced with environmental changes (Hussey *et al.*, 2015).

Brazil still has a low number of studies in marine acoustic telemetry in general, with most of them addressing elasmobranchs species (Ferreira *et al.*, 2013; Afonso & Hazin, 2014; Mendonça *et al.*, 2018) and only one study regarding bony fishes (Pinheiro *et al.*, 2018). So, in order to boost such kind of studies, a partnership with an international acoustic tracking network was established in 2015 (Iverson *et al.*, 2019; Pinheiro *et al.*, 2018) aiming mutual benefits among partners, through national and international data interchange and collaboration. In that sense, it is expected that incentives for MPA effectiveness studies and Brazilian participation on networks may help to fill this gap.

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