

## Research article

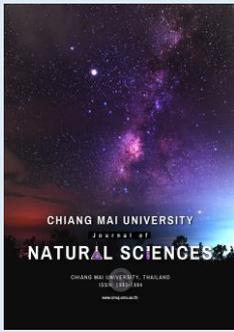
## A Systematic Literature Review of the Methodology Preference for Analyzing Eel (*Anguilla* spp.) Habitat

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**Abstract** Indonesia is rich in eel (*Anguilla* spp.) fishery resources, however, only sparse information is available regarding these resources, particularly the habitat preferences. These preferences have been studied severally using different methods, thus, there is currently no comprehensive description of the exact study methods. This study, therefore, aims to assay the development of research on eel habitat in the tropics, especially in Indonesia, and discover the most prevalent study method used between 2001 and 2020. This was carried out using a systematic literature review, defined as the process of identifying, assessing, and interpreting all available research evidence to provide answers to specific research questions. A total of 21 studies were selected for further analysis based on the specified inclusion and exclusion criteria. According to the results, current studies on eel habitat preferences focus on three topics: the ecology and behavior of eels during their lifecycle (52%), the relationship between eel morphology and habitat (19%), as well as the relationship between the time of metamorphosis and habitat (29%). Furthermore, 4 methods: Bio-morphology (29%), Otolith (57%), Ecological Studies (10%), and Gonadosomatic Index (5%), are commonly used. However, researchers suggest future research ought to be conducted more comprehensively. Therefore, more detailed ecological studies need to be carried out, together with otolith and bio-morphological studies.

**Keywords:** Systematic Literature Review, eels, habitat, and methodology preference for eel habitat



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## INTRODUCTION

Eels are one fishery resource commodity with high economic value, however, massive exploitation by humans threatens the existence of these resources in nature. Generally, these fishery resources are often captured during the estuarine glass eel phase of the life cycle, for instance, at the Cimandiri river estuary, Sukabumi, West Java, Indonesia (Triyanto et al., 2020). Subsequently, these fishery resources are cultivated to mature size and exported to countries with the world's highest demand for eels, including Japan, Korea, and China. Currently, there is a high demand for glass eels for cultivation, however, the abundance of several species is unknown (Yoshinaga et al., 2014).

Eels are catadromous animals, and therefore, migrate from marine to freshwater to grow, but return to the sea to spawn (Arai et al., 2001), and this is done uniquely (Arai 2016). This fish belongs to the family Anguillidae, as well as the genus *Anguilla*, with only 19 known species, and of these species, 13 are endemic to the tropics, while 6 are endemic to the subtropics (Seishi Hagihara et al., 2018; Arai and Chino, 2018). Indonesia is rich in eel (*Anguilla* spp.) fishery resources, however, only sparse information is available regarding these resources, particularly the habitat preferences. According to numerous theories, eels settle in freshwater within inland waters, however, certain eels remain in brackish waters (Arai and Chino, 2019).

This study, therefore, provides an overview of the development of research on eel habitats, particularly the methods used to study the habitat preferences within eels in the tropics, especially in Indonesia, using a systematic literature review compiled by studying literature on eel habitats in inland waters within Indonesia, published between 2001 and 2020.

## MATERIAL AND METHODS

### Objective Review

This review aims to identify and analyze the trends and methods used to research eel habitats in Indonesia.

### Review Method

This study used a systematic approach involving a literature review of the methods used to study the habitat preferences of eels in inland waters within Indonesia. A Systematic Literature Review is a method of reviewing existing research. Also, this article was written following the guidelines proposed by Kitchenham and Charters (2007), as well as (Wahono 2007).

### Research questions

These were defined to keep the review focused, and formulated using the PICOC (Population, Intervention, Comparison, Outcomes, and Context) criteria (Kitchenham and Charters, 2007). Table 1 shows the research question's PICOC structure.

**Table 1.** PICOC Summary.

Population	Methods
Intervention	Methods used to determine eel habitat preferences
Comparison	n/a
Outcomes	A widely used and suitable method for researching eel habitat
Context	Research in inland waters within Indonesia

Table 2 shows the research questions and motivation addressed by this literature review.

**Table 2.** The Research Questions.

ID	Research Question	Motivation
RQ1	What journals discuss the most about eel habitat?	Identify the most significant journals on Eel habitat preference ( <i>Anguilla</i> spp.)
RQ2	Who are the most active and influential researchers in the Eel habitat preference research area?	Identify the most active and influential researchers with the most significant contributions to the research area of Eel habitat preference ( <i>Anguilla</i> spp.)
RQ3	What are the most prevalent research topics regarding eel habitat?	Identify the trends in research topics related to Eel habitat preference ( <i>Anguilla</i> spp.)
RQ4	What is the most researched location/region in Indonesia?	Identify the most prevalent research location regarding Eel habitat preference ( <i>Anguilla</i> spp.)
RQ5	What is the most widely used method for researching eel habitat?	Identify the most prevalent research methods regarding Eel habitat preference ( <i>Anguilla</i> spp.)
RQ6	What are the advantages and disadvantages of this widely used method?	Identify the advantages and disadvantages of the most prevalent methods
RQ7	What improvements are required to improve the accuracy of future studies regarding Eel habitat preference?	Identify the proposed methods to improve research on Eel habitat preference ( <i>Anguilla</i> spp.)

## Search strategy

The Scopus database is extensive and complete, and was, therefore, selected for the literature search. Subsequently, the search keywords were determined and combined with Booleans ANDs and Ors, as shown below.

*(TITLE-ABS-KEY (eel) OR TITLE-ABS-KEY (eels) OR TITLE-ABS-KEY (yellow AND eels) OR TITLE-ABS-KEY (silver AND eels) AND TITLE-ABS-KEY (Anguilla) AND TITLE-ABS-KEY (habitat) AND TITLE-ABS-KEY (tropic) OR TITLE-ABS-KEY (Indonesia) OR TITLE-ABS-KEY (Malaysia) OR TITLE-ABS-KEY (Philippines) OR TITLE-ABS-KEY (south AND Asia))*

The search was also limited by the type (journals and proceedings) and year of publication (2001-2020). In addition, the search was limited to articles published in the English language, while the form of the review paper, as well as the book chapter, were used to provide further information.

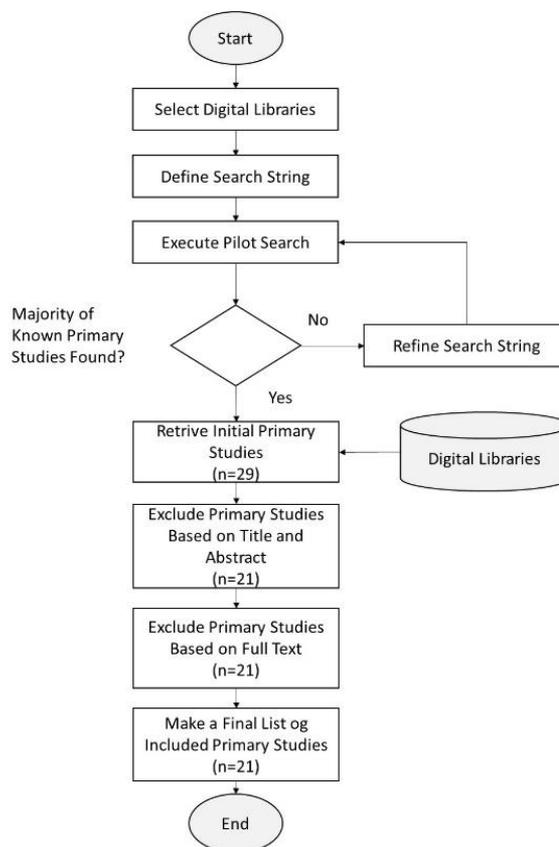
## Study selection

The results of the initial search using the digital library (Scopus) were further screened based on the inclusion and exclusion criteria shown in table 3.

**Table 3.** Inclusion and Exclusion Criteria

<b>Inclusion Criteria</b>	<ol style="list-style-type: none"> <li>1) Study of eel habitat from the estuary to the upstream and vice versa</li> <li>2) Studies on the behavior of eels in freshwater</li> <li>3) Freshwater eel ecology</li> <li>4) Studies in the tropics, especially Indonesia</li> </ol>
<b>Exclusion Criteria</b>	<ol style="list-style-type: none"> <li>1) Studies on eel cultivation</li> <li>2) Studies where eels are not the main object of research.</li> <li>3) Research on eel habitat at sea.</li> <li>4) Non-English publications</li> <li>5) Research on non-tropical eel species.</li> </ol>

Subsequently, the search results were stored and managed using Mendeley software. A total of 29 papers were selected and subjected to further selection to obtain 21 papers for the main study. These selected papers were then analyzed further to obtain the required information. Figure 1 shows a detailed illustration of the selection process, as well as the number of studies identified at each stage.



**Figure 1. A flowchart of the search and selection of primary studies.**

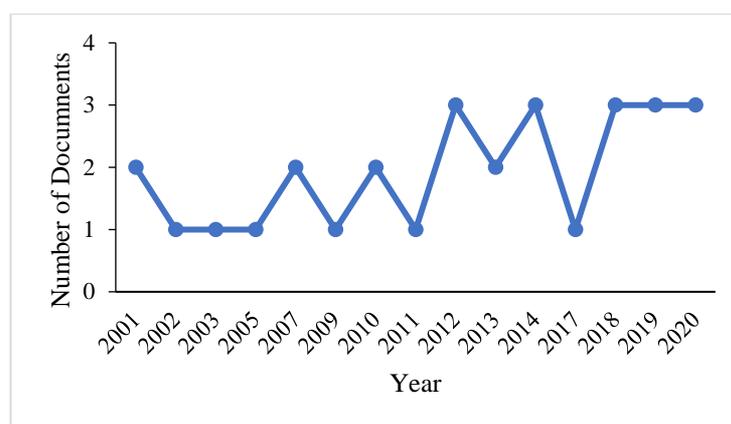
## Data extraction and synthesis

The main studies selected were extracted to collect data related to the research questions. Data synthesis was performed using the narrative synthesis method to obtain evidence, including quantitative and qualitative data. Tabulations were also used in this review according to the research questions. Meanwhile, several visualization tools, including bar charts, pie charts, and tables, were used to enhance the presentation of the results.

## RESULTS

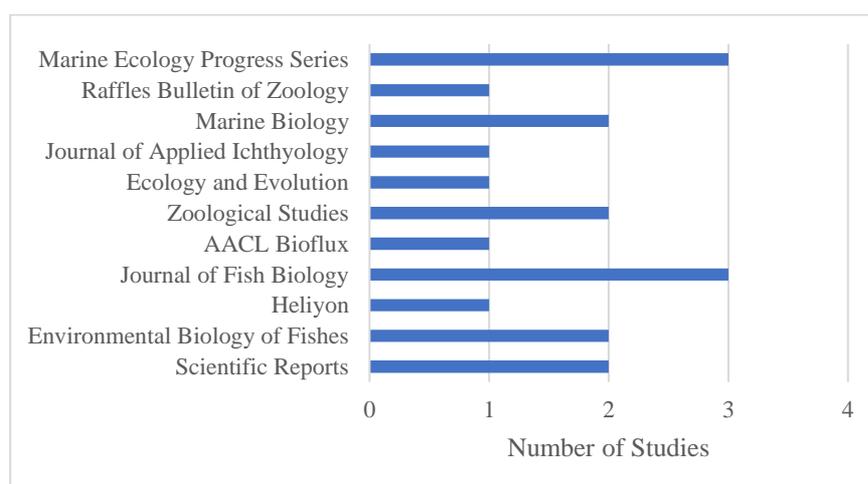
### Significant Journal Publication

Generally, research on eel habitat increased from 2005 to 2017, however from 2018 to 2020, this figure remained stagnant at 3 studies annually. Figure 2 shows the fluctuation of studies on eel habitat.



**Figure 2. The Trend of Selected Studies in 20 years.**

Figure 3 shows the most prevalent journal publications, based on the main selected studies on eel habitat.



**Figure 3. Journal Publications and Distribution of Selected Studies.**

Note: proceedings are not included in this graph.

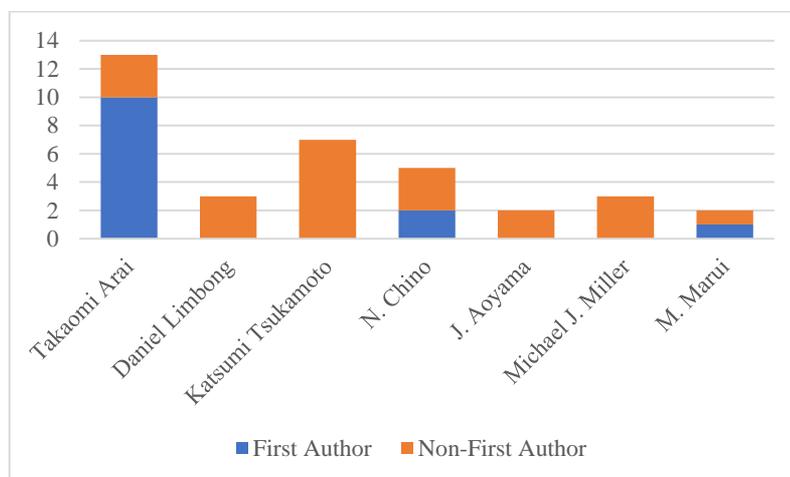
Table 4 shows the Scimago Journal Rank and Q category (Q1-Q4) from journal publications on habitat, based on the SJR ranking.

**Table 4.** The Scimago Journal Ranking (SJR) and Q category of the Selected Journals

No	Journal Publications	SJR	Q Category
1	Scientific Reports	1.24	Q1
2	Ecology and Evolution	1.17	Q1
3	Marine Ecology Progress Series	1.15	Q1
4	Marine Biology	0.93	Q1
5	Journal of Fish Biology	0.67	Q2
6	Environmental Biology of Fishes	0.65	Q2
7	Zoological Studies	0.64	Q2
8	Heliyon	0.46	Q1
9	Raffles Bulletin of Zoology	0.45	Q3
10	Journal of Applied Ichthyology	0.39	Q3
11	AACL Bioflux	0.28	Q3

## Most Active and Influential Researchers

Based on the main studies selected, the most active researchers with the most contribution to research on eel habitat were identified. Figure 4 shows researchers with several publications on eel habitat. The researchers were listed according to the number of publications included in the main study, with Takaomi Arai as the most influential and active researcher, followed by Katsumi Tsukamoto, Naoko Chino, Daniel Limbong, Michael J. Miller, J. Aoyama, and M. Marui.



**Figure 4. Influential Researchers and the Number of Studies.**

Note: only researchers with over one study are included in this graph.

## Research Related to Eel Habitat

Eel habitat is a commonly studied topic in fisheries because several eel species have been included in the global Red List issued by the IUCN Anguillid Specialist Sub Group (ASSG), including the *Anguilla anguilla* species, with an average annual abundance decline of 15%, from 1980 (Henderson et al., 2012), and the Critically Endangered (CE), *Anguilla japonica* with Endangered (EN) status, as well as several species found in Indonesia, for instance, *Anguilla bicolor* and *Anguilla celebesensis*, with Near Threatened (NT) status (Jacoby et al., 2015). According to the results, the following three topics are the most prevalent topics regarding eel habitat.

1. Studies on the ecology and behavior of eels during their lifetime
2. Study on the morphological relationship between eels and the habitat
3. Study of the relationship between metamorphosis time and habitat

The first topic was selected to determine the areas are used as habitats based on salinity recorded in otoliths or migration patterns (Arai et al., 2020; Arai and Chino, 2012; 2019; Briones et al., 2007; Arai et al., 2010), the migration habits of glass eels, as well as the influential environmental factors (Arai et al., 2020; Arai et al., 2017), and observe the environmental conditions during spawning (Arai et al., 2004; Arai and Chino, 2013).

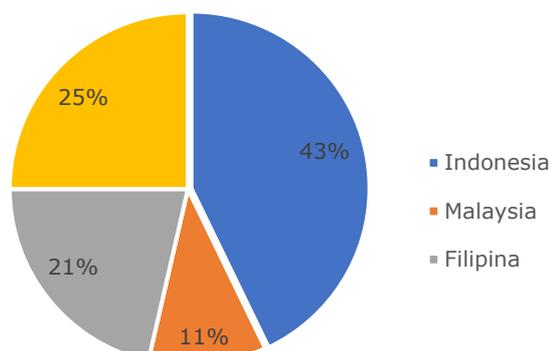
In addition, the second topic was selected to obtain information on the size, age and growth, habitat conditions of eels during their lifetime (Amrullah et al., 2019; Arai and Chino, 2019), as well as the relationship between morphology and ecology during migration (Hagihara et al., 2018).

The third topic was selected to explain the metamorphosis, migration, and distribution of eels using the microstructure and microchemistry of otoliths (Arai et al., 2001; 2002; 2003).

## The Most Prevalent Research Locations

Based on the results, 43% of the research sites were in Indonesia, 25% in Malaysia, 21% in the Philippines, while 11% were in temperate regions (Figure 5). In Indonesia, the most prevalent study areas are the Poigar river (North Sulawesi),

the Poso river and Poso Lake (Central Sulawesi), and the Segara Anakan (Central Java). Meanwhile, the most extensively studied species are *Anguilla marmorata* and *Anguilla bicolor bicolor* (Table 5).



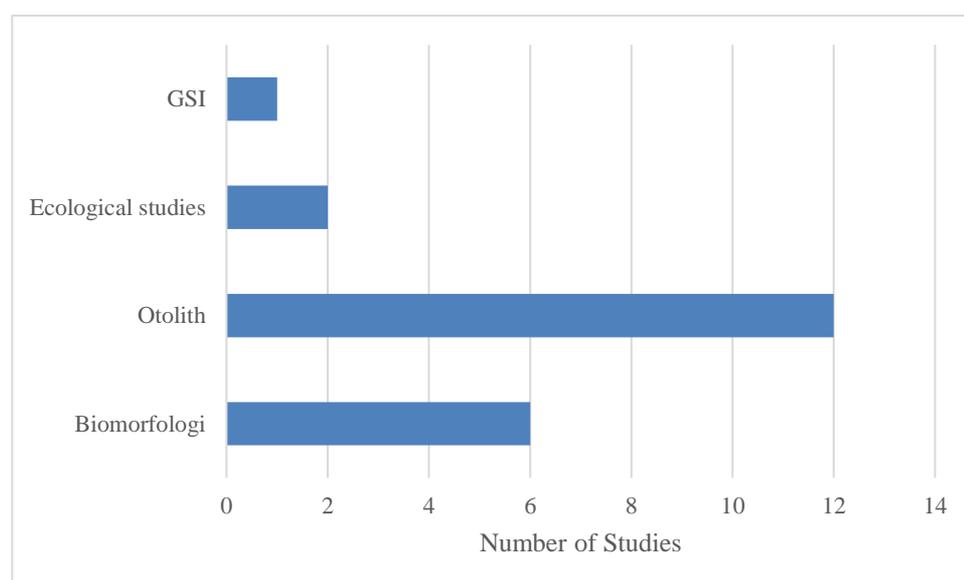
**Figure 5. The distribution of research location.**

**Table 5.** An overview of study locations and types of eel in the tropics.

Study location	Species of Eel	Country
Poigar River	<i>A. celebensis</i> , <i>A. marmorata</i> ,	Indonesia
Cimandiri	<i>A. marmorata</i> , <i>A. bicolor bicolor</i>	Indonesia
Lake Poso	<i>A. marmorata</i> , <i>A. bicolor bicolor</i> , <i>A. marmorata</i> , <i>A. interioris</i> , <i>A. Celebensis</i>	Indonesia
Segara Anakan	<i>A. marmorata</i> , <i>A. bicolor bicolor</i>	Indonesia
Sioyong river, Sausu river, Tambu river, Buol river (Sulawesi Tengah), Pondidaha river (Sulawesi Tenggara), and Likupang river (Sulawesi Utara)	<i>A. marmorata</i>	Indonesia
Penang Island and Langkawi Island Peninsular	<i>A. marmorata</i> , <i>A. bicolor bicolor</i> , <i>A. bengalensis</i>	Malaysia
Kurau river and Penang River	<i>A. bicolor bicolor</i>	Malaysia
Kuala Sanglang river, Batu Feringhi river, Teluk Bahang river, Pinang river, Air Putih river, Titi Teras river, Pulau Betung river, Bayan Lepas river, Pondok Upeh river, Perak river,	<i>A. bengalensis</i> , <i>A. bicolor bicolor</i>	Malaysia
Mindanao Island, Chica, and Cagayan river.	<i>A. japonica</i> , <i>A. marmorata</i> , <i>A. bicolor bicolor</i>	Philippines

### The Most Widely Used Study Methods

According to Figure 2, 4 methods were most widely used between 2001 and 2020 to research eel habitats during their lifecycle. Figure 6 provides a summary of all the methods identified in this study.



**Figure 6. The most widely used method for researching eel habitat.**

Based on the selected studies, the order of methods from least to most users is the GSI method, the ecological study method, the biomorphological method, and the otolith. The GSI method can show environmental conditions by using the gonadal maturation time approach, but this method is not very significant in describing the environment. Another method is biomorphology, this method uses an approach from the morphology of the eel, observing the body parts of the eel can explain whether the eel's environmental condition is suitable or not. The GSI method and the biomorphological method still require further analysis to determine the origin or habitat of the eel, one of the methods is using molecular genetic analysis (Arai, 2016).

The result of this review article shows that ecological studies are very few, this is because need large effort. This method directly observes the environmental parameters where the eels live. All abiotic and biotic parameters were observed. In Indonesia, information about the environmental characteristics of eels is still lacking, so this study is very much needed.

The otolith method is currently widely used to assess the habitat preferences of eels. Otolith is a structure containing calcium and is found in the inner ear of vertebrates, particularly the vestibular apparatus. For the study of eel habitat, a sagittal otolith, the largest of the three pairs in the inner ear, was used (Leander et al., 2013). These structures are used to study eel habitats because the structures contain calcite ( $\text{CaCO}_3$ ), strontianite ( $\text{SrCO}_3$ ), minor organic substances deposited periodically and retained metabolically throughout the lifecycle (Iizuka et al., 2002). Calcite ( $\text{CaCO}_3$ ) and strontianite ( $\text{SrCO}_3$ ) were used as standards to calibrate the concentrations of calcium (Ca) and strontium (Sr), respectively, in the otoliths.

### **The Advantages and Disadvantages of the Most Widely Used Methods**

The otolith method has several benefits, including providing an overview of the environmental conditions during the eel's lifetime. For instance, the study by Arai et al., (2020) using otoliths was able to describe the migration of *A. bicolor bicolor* species to saline or freshwaters in several periods. Furthermore, Briones et al., (2007), as well as Chino and Arai (2010) showed an analysis of the Sr:Ca ratio in otoliths is able to describe the migration pattern of eels between salinity gradients. This method also provides the benefit of estimating the age of eels using the number of annual rings on the otolith (Arai et al., 2020; 2003). However, this method requires a live individual to be killed (Hecht, 1980), therefore, care is needed in handling the specimens, especially in cases where few samples are observed.

## Further Research

The otolith method provides a detailed description of habitat and migration patterns during the eel's life cycle, however, this method only reveals the life history. Therefore, other data are required, for instance, detailed environmental factor data measured in the field (Arai et al., 2020) because this is useful in conserving certain areas (Hakim et al., 2019). In addition, morphological data from eels are required (Amrullah et al., 2019; Arai et al., 2020; Arai and Abdul Kadir, 2017; Arai and Chino, 2019; Hagihara et al., 2018; Yoshinaga et al., 2014), to determine other aspects, including gonad maturity, length and weight, and eel growth in relation to habitat (Arai and Chino, 2013).

Researchers suggest more comprehensive and in-depth methods for future studies. Currently, studies on ecology are not comprehensive enough, therefore, studies on the physical environment are required because of the threat of future changes in habitat, water quality, and ecosystem, due to development (Arai 2016). Also, information on the distribution of eel habitats, both spatially and temporally, especially in Indonesia, are highly required.

## CONCLUSION

Based on the results, 43% of the main selected studies were conducted in Indonesia, 25% in Malaysia, 21% in the Philippines, while about 11% were carried out in temperate regions. However, this study used research on eel habitats in the tropics as a comparison.

Furthermore, four research methods were discovered to be most commonly used, and these are gonad somatic index (GSI) (5%), Ecological Studies (10%), Otolith (57%), as well as Biomorphology (29%). The otolith method has the capacity to predict the age, environmental conditions during settlement, or migration of an eel during the life cycle, and is, therefore, widely used. However, further analysis, including environmental and morphological studies are required to improve the accuracy of research on eels.

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## AUTHOR CONTRIBUTIONS

All authors contributed to this article and approved the published version of this manuscript. Aldiano Rahmadya was the corresponding author, while Iwan Ridwansyah, Dini Daruati, Triyanto, Asih P Dewi, Dudi M Wildan, and Ali Rahmat were contributing members.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

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