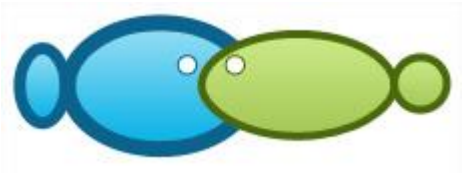

A comprehensive systematic review on Nike fish (Gobiidae) research trends: Native species in Gorontalo waters, Indonesia

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Abstract. Nike fish, a native amphidromous species inhabiting Gorontalo waters, faces a significant threat due to the massive exploitation of its larvae during their migration in marine environments. This predatory pattern poses a serious risk to the sustainability of Nike fish populations in their natural habitat. Furthermore, the dearth of comprehensive bioecological investigations, including species identification, has left important aspects of Nike fish biology largely unexplored. To address these knowledge gaps, we conducted a systematic review of Nike fish research following the established PRISMA guidelines. Utilizing Google Scholar, Semantic Scholar, and Scopus databases, we meticulously combed through the available literature from April to May 2022. Our rigorous screening process initially yielded a total of 400 entries, ultimately identifying 28 distinct papers suitable for in-depth analysis. Our findings reveal a diverse array of research on Nike fish, laying the foundation for further explorations into this species. Notably, there is a discernible upward trend in Nike fish research, with an increasing number of publications in recent years, particularly in 2017 (2 papers), 2018 (4 papers), 2019 (5 papers), and 2020 (7 papers). Predominantly, these studies delve into the morphology of Nike fish, while select publications delve into molecular analysis, species composition, and distribution patterns. Despite these commendable efforts, much remains to be uncovered regarding Nike fish characteristics and migration patterns. A potential bottleneck to future progress lies in limited collaboration with international researchers and language barriers. Nevertheless, recent years have witnessed the promising initiation of a burgeoning research trend focused on Nike fish.

Key Words: amphidromous fish, marine larval migration, Nike fish, research trends, species composition.

Introduction. In the water of Gorontalo, Indonesia, the term "Nike fish" refers to the amphidromous Gobiidae fish group. These native fish do not represent a single species throughout their entire life cycle. Instead, the term encompasses only the larval stage, during which these fish form schools in the waters. It is strongly suspected that these schools consist of multiple species or species complexes. While some authors have suggested that Nike fish in Gorontalo is endemic (Pasisingi & Abdullah 2018; Zakaria 2018; Pasisingi et al 2021), others have found similar fish types in different areas, challenging their endemic status (Nurmadinah 2016). Nevertheless, Nike fish in Gorontalo waters exhibit distinct composition compared to other regions.

The larval migration of Nike fish in Gorontalo waters experiences significant fishing activity due to their popularity as a food source, a favorite culinary item, and even regional export commodities (Yusuf 2011; Liputo et al 2013; Pasisingi & Abdullah 2018). This increased demand has elevated the economic value of Nike fish. The data from the Department of Fisheries and Marine Affairs (DKP) of Gorontalo Province (2011) shows that during the 2009-2010 period, the catch reached approximately 181 tons. However,

excessive and continuous fishing activities, particularly during the larval stage, can lead to overfishing, especially growth overfishing, as many young fish are caught before reaching adulthood. Growth overfishing conditions can occur because many fishing activities catch fish that are too young, so there is no opportunity to reach adult size (Caillouet et al 2009). This exploitation pattern, especially during the critical larval stage, poses a threat to the survival of the Nike fish population in the wild. The schooling Nike fish in their larval stage plays a vital role in the recruitment process, yet their supply still relies on natural catches.

Effective management efforts are essential to ensure the sustainability of Nike fish populations. To formulate successful management and conservation strategies, comprehensive data on Nike fish biology, ecology, and fisheries are required. This includes information on species identity, population biology, habitat, and migration patterns. Thus, conducting a systematic review of Nike fish research is the first step towards acquiring this essential knowledge.

Material and Method

Data sources and search strategy. We adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines to identify pertinent articles and reports concerning Nike fish. Between April and May 2022, we executed searches across various databases, namely Google Scholar, Semantic Scholar, and Scopus, utilizing the Publish or Perish (PoP) application. Our search queries encompassed keywords such as "Nike fish (Gobiidae) Indonesia" and "Amphidromous goby larva Indonesia".

Study selection. Employing the pre-established search terms, we gathered relevant articles, eliminated duplicates, and compiled a final list for detailed scrutiny. The selection process aimed to pinpoint articles with comprehensive investigations into Nike fish. Before inclusion, we meticulously assessed the titles and abstracts of all papers acquired through the systematic search to identify potentially relevant ones. Subsequently, we conducted a thorough examination of the full texts of these potentially relevant articles. Any articles deemed by the reviewers to lack substantive discussions of Nike fish during the title and abstract review were excluded. Pertinent articles meeting the following criteria were identified: 1) articles available in English or Indonesian; 2) articles with full-text accessibility; 3) data retrieved from the Publish or Perish (PoP) application or software (https://harzing.com/resources/publish-or-perish).

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Analysis. We extracted descriptive information from the selected articles, including temporal aspects, contextual and geographical relevance, data sources and their availability, study types, and methodologies. Using a deductive approach, we extracted information about the specific Nike fish types, geographical emphasis, research methods/study designs, and findings. Data processing was accomplished using Microsoft Excel. Additionally, we employed an inductive approach to identify emerging themes from the articles and further dissect the concepts. The key themes encompassed species composition, morphology and molecular identification, habitat, and migration. The extraction of these themes involved iterative processes, necessitating continual comparisons across the papers.

Results

Descriptive analysis of the literature. In our comprehensive search, we identified 28 articles for thorough review out of 400 distinct articles retrieved through our systematic search (Figure 1).

The comprehensive list of papers is presented in Table 1. Among these 28 articles, peer-reviewed journals constituted the predominant source, followed by undergraduate theses and conference papers (Figure 2). Twelve articles were composed in Indonesian, while 16 were in English. The data collection methods employed comprised desk studies, fieldwork, laboratory research, and combinations thereof (Figure 3).

The bar chart in Figure 2 illustrates the distribution of publications by article type. As evidenced, journal articles significantly predominated at 79% (n=22), followed by undergraduate theses at 14% (n=4), and conference papers at 7% (n=2). This distribution underscores the preference for journal articles as the primary medium for Nike fish research.

Figure 3 graphically represents the methodologies employed for data collection. The combination method was the most frequently used approach, accounting for 72% (n=20) of the research, primarily focusing on morphology and genetics. Desk studies constituted 7% (n=2), primarily exploring topics related to morphology, habitat, feeding habits, life cycle, migration, and biodiversity of Nike fish in Indonesia. Field investigations represented 7% (n=2) of the research and predominantly centered on migration, species diversity, habitat, and morphology. The remaining 14% (n=4) pertained to laboratory-based research, particularly post-harvest studies concerning the quality of Nike fish.

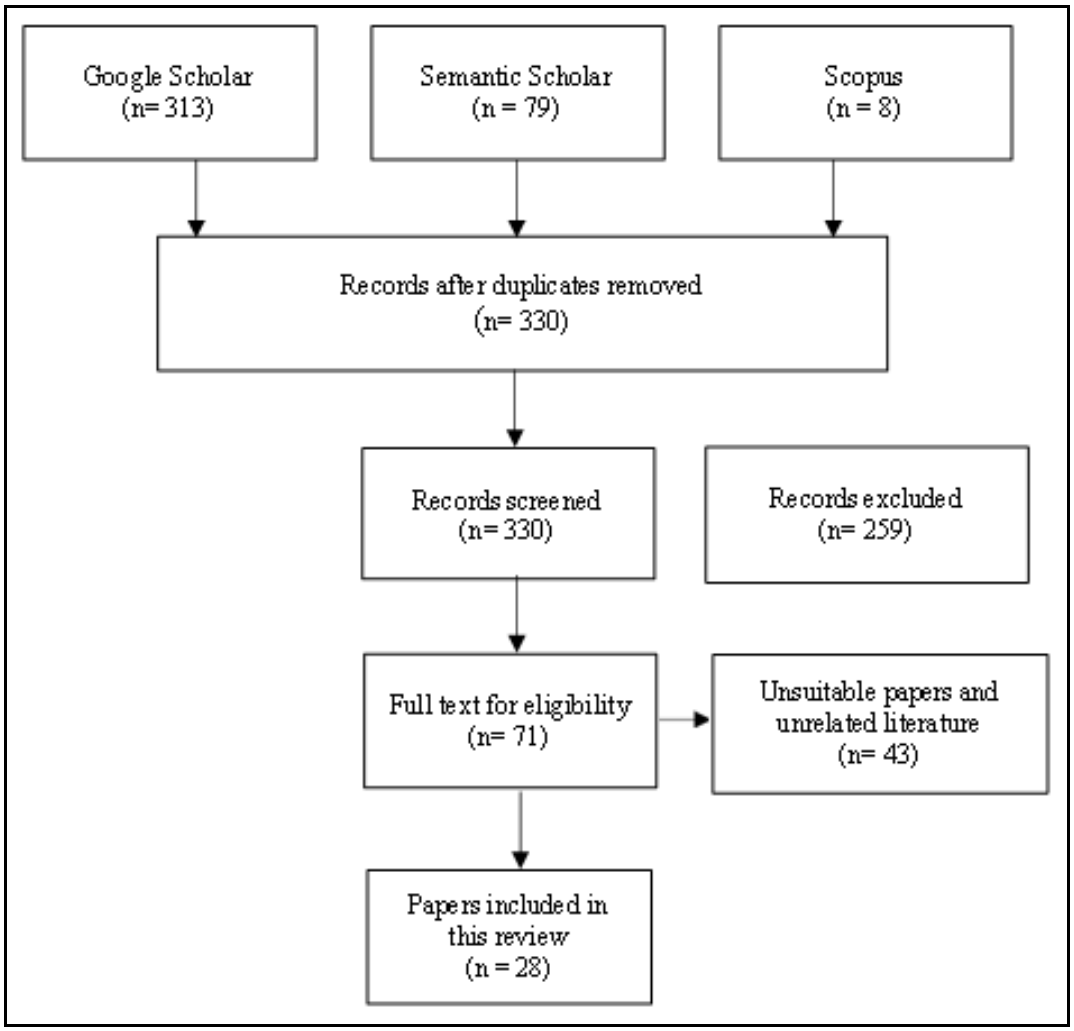

Figure 1. PRISMA diagram summarizing the number of papers included/excluded in the process.

Table 1

Summaries of the 28 articles included in the review

Type	*Citation*	*Main topic*	*Method*
Journal article	Nurjirana et al (2019a)	Morphology	Combination
	Pasisingi et al (2020a)	Morphology	Combination
	Muthiadin et al (2020)	Morphology	Combination
	Pasisingi et al (2021)	Morphology	Combination
	Sahami et al (2019b)	Morphology, genetics, species composition	Combination
	Nonutu et al (2021)	Processed food	Laboratory
	Salindeho (2021)	Bioecology	Desk Study
	Abdullah & Mutia (2020)	Processed food	Laboratory
	Arisanti (2018)	Processed food	Laboratory
	Ariany & Putalan (2021)	Processed food	Laboratory
	Pasisingi & Abdullah (2018)	Habitat, behavior	Combination
	Olii et al (2017)	Habitat, distribution	Combination
	Salindeho et al (2022)	Migration	Combination
	Nurjirana et al (2022)	Migration	Field
	Pasisingi et al (2020b)	Genetics	Combination
	Sahami et al (2019a)	Morphology, molecular analysis	Combination
	Sahami & Habibie (2021)	Species diversity	Combination
	Sahami et al (2020)	Morphology, genetics	Combination
	Olii et al (2019)	Genetics	Combination
	Pangemanan et al (2020)	Morphology, genetics	Combination
	Sahami et al (2020)	Genetics, morphology	Combination
	Salam et al (2016)	Biology, fisheries	Combination
Thesis	Nurmadinah (2016)	Morphology	Combination
	Usman (2016)	Genetics	Combination
	Andriyani (2018)	Morphology	Combination
	Azman (2018)	Bioecology	Combination
Conference paper	Muthiadin et al (2017)	Morphology	Desk study
	Nurjirana et al (2019b)	Species diversity, habitat, morphology	Field

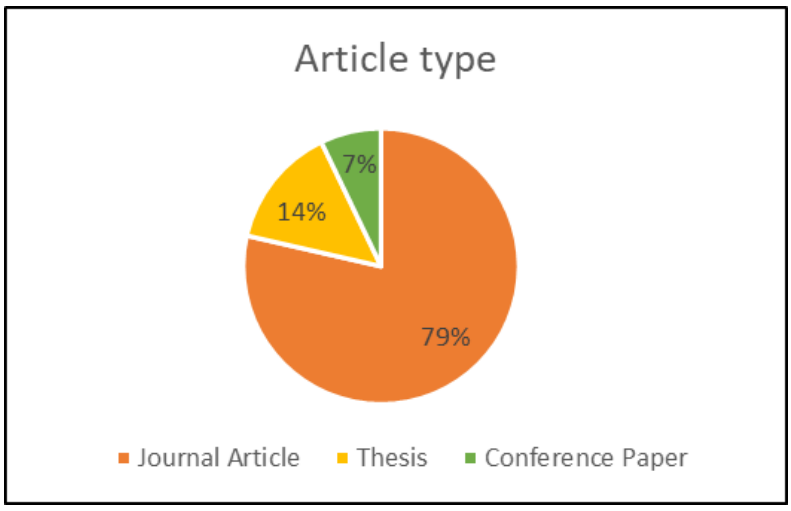

Figure 2. Number of publications based on article type.

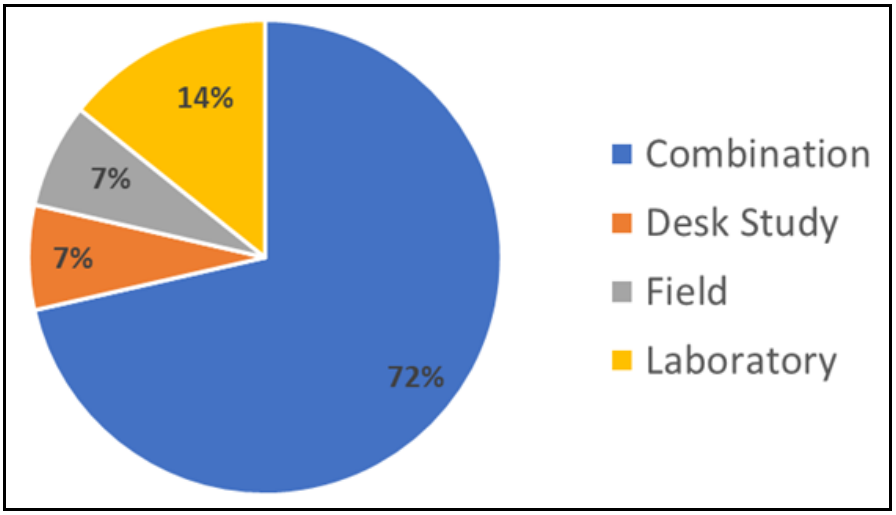

Figure 3. Data collection methods.

Trends and distribution of publications. The geographical distribution of Nike fish research exhibited a concentration in Sulawesi, notably in Gorontalo, with 17 articles, while fewer studies were conducted in West Sulawesi (6 articles), North Sulawesi (2 articles), and other regions (3 articles) (Figure 4). Our data collection spanned from 2016 to 2022, with the highest number of publications occurring in 2020 (Figures 5 and 6).

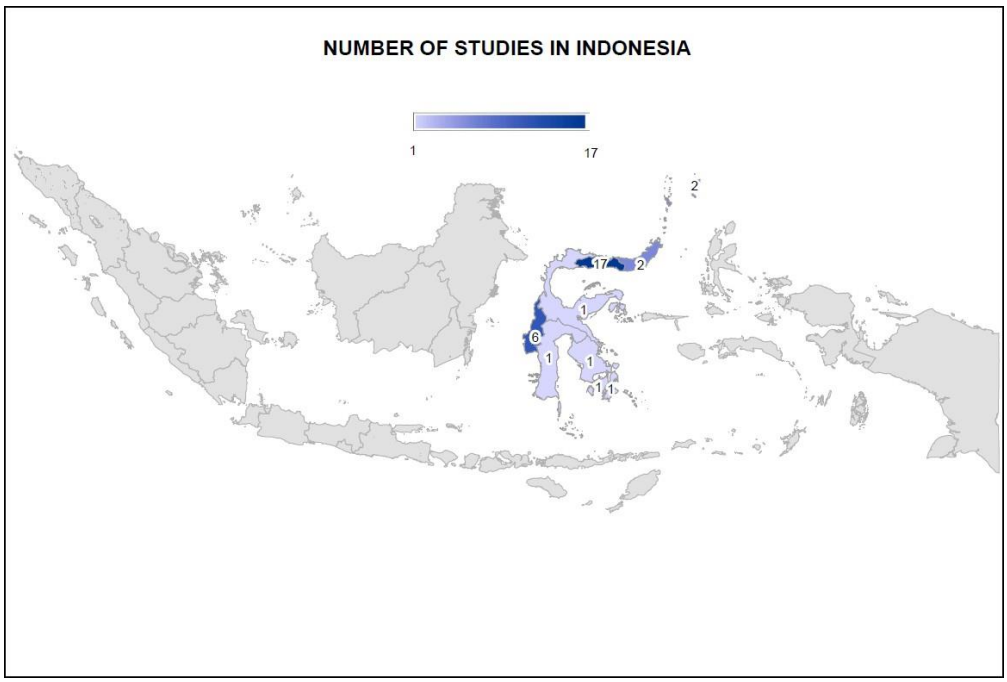

Figure 4. Number of research articles based on geographical context.

Irrespective of the native habitat of Nike fish, several studies have been conducted beyond Gorontalo, including West Sulawesi and North Sulawesi. The earliest publications, as recorded in this study, originated from Gorontalo and Polewali (Nurmadinah 2016; Salam et al 2016; Usman 2016), primarily addressing fundamental aspects such as morphology and genetics. West Sulawesi emerged as another prominent region outside of Gorontalo, focusing on morphology, genetics, species composition, and migration (Andriyani 2018; Azman 2018; Nurjirana et al 2019a; Nurjirana et al 2019b; Muthiadin et al 2020). The scarcity of Nike fish research in other regions underscores the need for

expanded investigations to provide comprehensive data and facilitate more effective management processes across diverse regions and life stages.

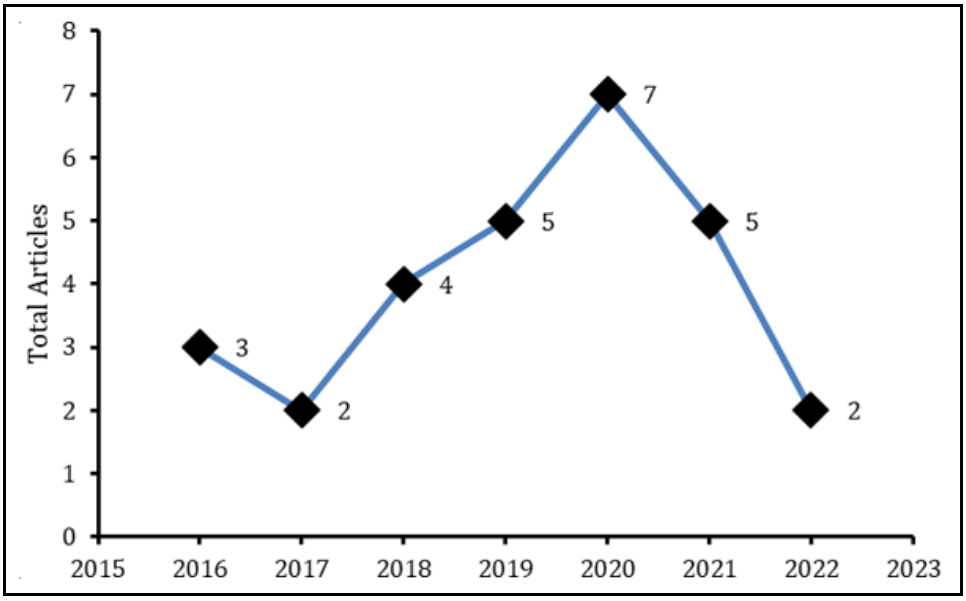

Figure 5. Trends in the number of publications over the years.

The trend in the number of publications over the years is depicted in Figure 5, indicating a continuous stream of research from 2016 to 2022, with the highest number of publications occurring in 2020. This suggests a sustained commitment to the study of Nike fish, with the data generated serving as fundamental information for future conservation policies.

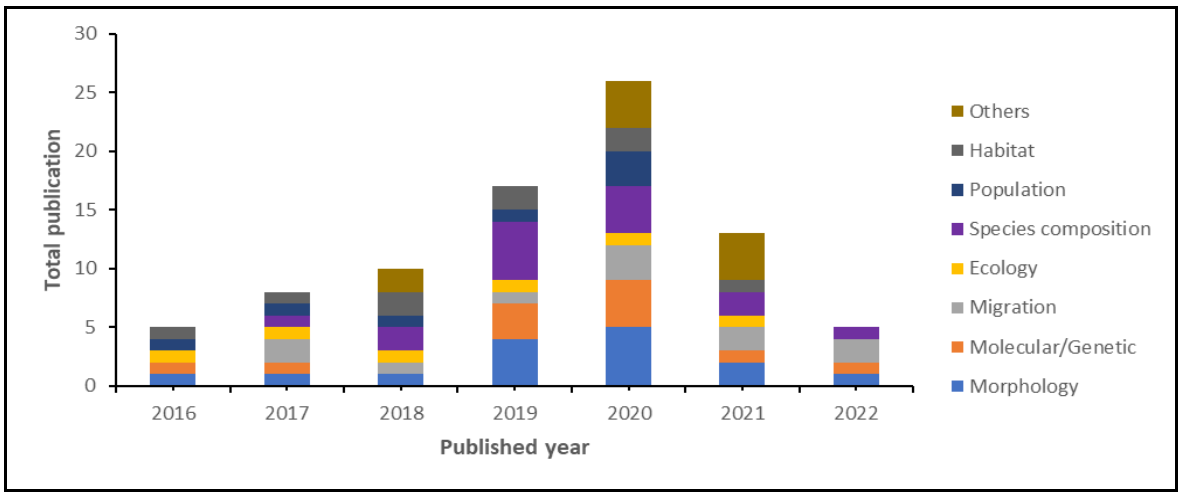

Figure 6. Trends and thematic composition of Nike fish research.

Figure 6 provides insights into the thematic composition of Nike fish research. Researchers have explored a diverse range of topics, including habitat, population, species composition, ecology, migration, molecular or genetic aspects, and morphology. In 2019, research predominantly revolved around species composition and morphology, while in 2020, the focus shifted to morphology and species composition. This trend reveals a prevalent emphasis on morphology and genetics in Nike fish research, leaving habitat and ecology relatively unexplored. Research concerning ecology and habitat is of paramount significance, particularly in understanding the spawning and growth locations of these fish. A similar need for comprehensive research on a species' habitat and

ecology is highlighted in studies on eels in Indonesia (Rahmadya et al 2022). In contrast, 2021 saw an increased focus on topics outside of the primary thematic categories, indicating diversification in Nike fish research.

Discussion. The term "Nike fish" designates a group of diminutive fish initially believed to be endemic to the waters of Gorontalo, North Sulawesi. Nonetheless, several studies have demonstrated that Nike fish encompass various species within the Gobiidae family, particularly *Awaous* sp. (Olii et al 2017). Similar fish of this kind have also been documented in other parts of Sulawesi. For instance, at the Tondano River estuary, species such as *Sicyopterus pugnans*, *Awaous grammepomus*, and *Sicyopterus lagochepalus* were identified, while in the Poigar river estuary, *S. pugnans* and *A. grammepomus* were observed. Additionally, analogous fish have been encountered in Lake Tondano, with research indicating that the fish in the lake belong to the introduced species *Ophioleotris aporos* (Pangemanan et al 2020).

Among the Nike fish inhabiting Gorontalo waters, *Awaous melanocephalus* is the most frequently studied species, as evident from multiple investigations (Nurmadinah 2016; Salam et al 2016; Olii et al 2017; Pasisingi & Abdullah 2018; Sahami et al 2019a). These fish typically measure between 2 to 8 cm in length. Notable morphological traits of this species include an elongated body shape, a terminal-positioned mouth, the absence of scales, an erect tail fin, thoracic pectoral fins, a single dorsal fin, and melanophores featuring a horizontal pattern (Nurmadinah 2016). Nike fish undergo distinct life stages, commencing with the laying of eggs in rivers, followed by the juvenile phase in the sea, and ultimately, their return to freshwater habitats (Olii et al 2017).

A study conducted by Pasisingi et al (2020a) unveiled differences in the morphology of Nike fish across various locations. Larval-phase fish found in marine waters exhibit transparent bodies, slender dorsal and pectoral fins, and visible yolk sac remnants. Their eyes are characterized by black pigmentation encircled by white rings. In contrast, post-larval-phase fish in estuarine environments possess white bodies with increased opacity, and their eyes no longer exhibit the white ring pattern. Juvenile-phase fish in rivers are distinguished by darker coloration, well-developed fins, and prominent black melanophore stripes. This study's findings strongly suggest that morphological variations are closely linked to the location of discovery, likely influenced by distinct life stages and environmental conditions. Unfortunately, the study does not specify the names of the species investigated. Given the diversity of species comprising Nike fish schools, further research dedicated to examining morphological changes in different species is warranted.

In recent times, in-depth species studies of Nike fish within Gorontalo waters have been undertaken (Sahami et al 2020; Pasisingi et al 2020a; Pasisingi et al 2021). Approximately 2523 samples were meticulously analyzed, incorporating morphometric characteristics and melanophore pattern categorization, subsequently confirmed through molecular biology analysis. This comprehensive investigation revealed that Nike schooling species in Gorontalo waters primarily belong to the Gobiidae family, including species such as *Sicyopterus parvei*, *S. cynocephalus*, *S. longifilis*, *S. lagocephalus*, and *Stiphodon semoni*. Additionally, fish from the Eleotridae family, notably *Belobranchus belobranchus*, were identified. Interestingly, the commonly reported *A. melanocephalus* species was conspicuously absent in this study, possibly due to variations in sampling periods. Typically, *A. melanocephalus* is observed between June and November, whereas these particular studies occurred during January and February.

It is essential to acknowledge that the term "Nike fish" is regionally specific to the Gorontalo area, whereas in West Sulawesi, the term "Penja fish" is employed to describe similar Gobiidae fish species. Earlier research suggested that these represented distinct species of fish (Nurmadinah 2016). However, recent studies have indicated that the Penja fish group found in West Sulawesi shares remarkable similarities with the group found in Gorontalo, specifically *S. longifilis* and *S. pugnans* (Nurjirana et al 2019a; Muthiadin et al 2020). Nike fish and Penja fish exhibit comparable physical characteristics.

An insightful publication concerning the genetic variation of Penja fish in Poliwari Mandar, West Sulawesi waters, and Nike fish (*Awous* sp.) in Gorontalo, North Sulawesi, has emerged (Usman 2016). The genetic analysis highlights the existence of variety within a species. The specific outcomes reveal that Penja and Nike fish exhibit low genetic distance values and a high similarity index, indicating a close genetic relationship. Nevertheless, the article's methodology lacks clarity, precluding definitive conclusions regarding the genetic population of Nike fish.

There are a total of 11 publications within the migration category. The noteworthy peak occurred in 2020 with three publications, followed by a slight decline thereafter. These migration-focused publications revolve around Nike fish, a species known for its amphidromous migratory behavior (Muthiadin et al 2017; Pasisingi & Abdullah 2018). Amphidromous fish, upon reaching maturity, engage in a distinctive migration pattern: they spawn in freshwater, and their eggs or newly hatched larvae are carried downstream to the sea, where they exist as planktonic juveniles before eventually returning to freshwater habitats to reach adulthood and reproduce (Salindeho 2021; Salindeho et al 2022). This migratory process is intricately tied to the various developmental stages of the fish.

One notable study, conducted in 2019 (Sahami et al 2019a), delved into the morphological alterations that Nike fish undergo during their migration from the ocean to freshwater rivers. The research uncovered that as *Belobranchus segura* species migrated from the ocean to rivers, their melanophores' patterns underwent notable changes. Specifically, while in the sea, the melanophores were not evenly dispersed, but their distribution altered upon entry into the river. Additionally, another study (Nurjirana et al 2022) reported a higher degree of morphological diversity among Nike fish populations during the rainy season compared to the dry season. It is evident that Nike fish exhibit variations in their morphology and coloration depending on their location within the aquatic environment and the duration of their stay. Notably, low salinity water appears to play a pivotal role in guiding the migratory behavior of Nike fish towards upper regions and serves as a trigger for metamorphosis (Olii et al 2017).

Research pertaining to migration seasons has been extensively documented in West Sulawesi (Olii et al 2017; Muthiadin et al 2020; Nurjirana et al 2022). These investigations have revealed that amphidromous goby postlarvae (Penja) recruitment is sporadic, and not all rivers serve as migration routes. For instance, Penja fish of the *Sicyopterus* genus in the Karama River, West Java, have demonstrated the capability to migrate upstream despite reaching elevations well above sea level (<100 m). Nike fish larvae have been observed migrating for several days.

One publication specifically explores the migratory behavior of Nike fish schools in Tomini Bay Paguyaman, Gorontalo. In this study, *Eleotris* pelagic larvae were observed using seawater tides to migrate to river areas during nighttime. Notably, *E. fusca* exhibited the ability to migrate upstream against river water flow currents into freshwater, while *E. melanosoma* and *E. acanthopoma* settled in the upper regions of areas influenced by tides (Sahami & Habibie 2021). However, it remains uncertain whether all Nike fish successfully reach freshwater rivers, given the challenges associated with tracking the migration of fish larvae along river courses.

An investigation into the species composing Nike fish populations was undertaken in Bone River, Gorontalo, with a focus on tracing adult gobies inhabiting freshwater environments (Pasisingi et al 2020b). *Awaous ocellaris* and *Belobranchus belobranchus* were strongly suspected to be the two species constituting the goby schools during their migration into freshwater habitats in the adult stages. Additionally, research from Sahami & Habibie (2020) has confirmed that Nike is an amphidromous species, supported by the discovery of the adult phase of six species composers of Nike fish assemblages; *Sicyopterus longifilis*, *S. lagocephalus*, *B. belobranchus*, *B. segura*, *Bunaka gyrinoides*, and *Stiphodon semoni* in Bone Bolango River based on the DNA COI mitochondria analysis.

Research gap. To date, research on Nike fish remains limited in scope within Indonesia, with the bulk of studies concentrating solely on Sulawesi, specifically in the regions of

Gorontalo, West Sulawesi, and North Sulawesi. This is despite the fact that various locations across Indonesia have reported the presence of gobies species. Moreover, the comprehensive cataloging of Nike fish species assemblages in Gorontalo is still an ongoing process, with numerous potential new species records that could contribute to the makeup of Nike schooling.

The identification of larval species has primarily relied on DNA barcoding due to the inherent difficulties in morphological identification. These challenges arise from various factors, including the presence of different larval stages within the same species, leading to alterations in morphological characteristics (Sahami et al 2019b). To discern between morphological variations at different life stages, additional research is imperative, encompassing investigations into Nike's life cycle stages and spawning locations.

Studies from Japan (Maeda & Tachihara 2010; Yamasaki et al 2011) have demonstrated the feasibility of morphological identification of many larval gobies to the genus level. Some research has even managed to differentiate between two species during the larval stage by employing a combination of DNA barcoding and morphological analysis, drawing comparisons with the adult phase (Nurjirana et al 2021). However, such differentiation is contingent upon the knowledge that the sample is in the post-larval stage.

The dearth of research on Nike/Penja in Indonesia underscores the need for more extensive surveys across various regions. These surveys should aim to determine the species present and their abundance throughout different periods of the year, as indicated by studies conducted by Sahami & Habibie (2021), which revealed varying species compositions within Nike/Penja schools at different times.

In-depth investigations into Nike/Penja during the adult phase are essential, encompassing aspects of morphology and reproductive bioecology, including the spawning phase. This approach would help in predicting the presence of Nike/Penja species during specific timeframes accurately. Additionally, well-established and validated morphological data for adult Gobidae and Eleotridae within their respective regions, coupled with genetic data deposited in databases, are crucial for authenticating Nike species collected in their larval stage. Such data can also aid in refining larval morphological differentiation.

Given the diversity of species found within Nike/Penja catches, which highlights significant variations between Gorontalo and West Sulawesi, there is ample opportunity for comparative studies across various locations. Undertaking a comprehensive study on Nike/Penja in diverse regions across Indonesia can serve as a benchmark for management efforts aimed at preventing overexploitation and ensuring the long-term sustainability of Nike fish populations.

Conclusions. The research trends on Nike/Penja species in the last five years have shown an increase and mostly discuss morphology and genetics (61%), fishery processing (21%), habitat and ecology (14%), and about 4% migration. Nike research in Indonesia is mostly concentrated geographically in Gorontalo (17 articles), West Sulawesi (6 articles), North Sulawesi (2 articles), and others (3 articles). However, because research and studies on Nike/Penja are relatively few and limited, many research gaps must be studied further, especially the species that compose it, its bio-ecology, abundance and population dynamics. In addition, the potential for research on Nike/Penja in different regions of Indonesia also needs to be explored further.

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Conflict of Interest. The authors declare that there is no conflict of interest.

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