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Status, Research Gaps, and Conservation Challenges of *Hemiscyllium* spp. Species in Indonesia: A Bibliometric Analysis

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ABSTRACT

The genus *Hemiscyllium*, commonly known as "Hiu Berjalan" (walking sharks), comprises nine species which are mostly endemic to Indonesia and Papua New Guinea, with a restricted geographic distribution. This study evaluated the status, limitations, and challenges of *Hemiscyllium* research in Indonesia through a bibliometric approach, based on 88 Scopus-indexed publications (1993–2024) analyzed using Biblioshiny (bibliometrix v4.3.0) and VOSviewer 1.6.19. Results indicate a moderate annual publication growth rate of 3.61%, with 46.59% involving international collaboration, but relatively low participation of Indonesian researchers. Temporal and thematic mapping showed that research was concentrated in the period 2015–2023, predominantly focusing on physiological adaptations to hypoxia in *H. ocellatum*, while ecological, population, and conservation studies remained limited. Geographical analyses highlighted a strong concentration of research in eastern Indonesia (Halmahera, Raja Ampat, and Cenderawasih Bay), with western and central regions underrepresented. Taxonomic and disciplinary analyses revealed a predominance of single-species physiological studies, with limited integration into ecosystem or management contexts. Keyword mapping identified three main research clusters: stress physiology, habitat ecology, and species conservation. Current conservation mechanisms largely rely on marine protected areas and CITES listings, yet lack species-specific management strategies. These findings underscore the need to address research gaps, strengthen national scientific contributions, foster local–international collaborations, and integrate scientific evidence into targeted conservation policies for *Hemiscyllium* spp. in Indonesia.

INTRODUCTION

The walking sharks (*Hemiscyllium* spp.), also known in Bahasa as Hiu Berjalan or Hiu Epaulette, are small benthic sharks belonging to the family Hemiscylliidae. They are endemic to the Indo-Australian region, particularly the marine waters of Indonesia, Papua New Guinea, and northern Australia. The genus currently comprises nine formally described species: *H. trispeculare*, *H. ocellatum*, *H. freycineti*, *H. halmahera*, *H. galei*, *H. strahani*, *H. michaeli*, *H. henryi*, and *H. hallstromi* **(Allen *et al.*, 2016; Dudgeon *et al.*, 2020)**. These species inhabit coral reef flats, seagrass beds, and mangrove-fringed lagoons, typically at depths of 0–20 meters. Coral reef ecosystems play a vital ecological role as spawning grounds, nursery habitats, and foraging sites for marine organisms **(Mujiyanto *et al.*, 2023)**, including *Hemiscyllium*. A distinctive trait of this genus is its ability to "walk" along the substrate using modified pectoral and pelvic fins **(VanderWright *et al.*, 2021)**. This adaptation, closely tied to coral reef habitats, enables survival in isolated reef systems with low oxygen availability. However, coral reefs, as the primary habitat for walking sharks, are increasingly threatened by unsustainable fishing and tourism practices **(Mujiyanto *et al.*, 2023)**, jeopardizing the survival of this habitat-specialist group.

Although Indonesia is home to most *Hemiscyllium* species, research efforts remain fragmented and limited in scope. Foundational taxonomic and phylogenetic studies laid an essential groundwork **(Allen & Erdmann, 2008; Allen, 2013; Dudgeon *et al.*, 2020)**, yet ecological and conservation studies on the population or landscape scale are scarce. Notable contributions include morphometric and genetic analyses of *H. halmahera* **(Madduppa *et al.*, 2020; Mu'min *et al.*, 2021)**, population structure analysis of *H. freycineti* in Raja Ampat **(Widiarto *et al.*, 2020)**, and abundance and growth studies of *H. galei* in Manokwari **(Insani *et al.*, 2022)**. In North Maluku, surveys on *H. halmahera* have been conducted **(Akbar *et al.*, 2023a)**, yet substantial gaps remain—for example, no population structure data exist for *H. halmahera* around Morotai Island, and no demographic studies have been undertaken on small equatorial islands such as Tawabi, where unique environmental conditions may influence population dynamics **(Akbar *et al.*, 2025)**. Consequently, the Indonesian research landscape on *Hemiscyllium* spp. remains underrepresented compared to global efforts, and the fragmented nature of existing studies hinders the development of evidence-based conservation strategies.

Ecologically, walking sharks function as mesopredators, shaping reef communities by regulating benthic invertebrate populations **(Heupel & Bennett, 1998)**. Their behavioral ecology, including nocturnal foraging and tide-linked movements, reflects strong environmental specialization **(Allen & Erdmann, 2008)**. Besides, they exhibit remarkable hypoxia tolerance, allowing persistence in tidepools and shallow reef flats **(Routley *et al.*, 2002)**. However, these habitats are increasingly threatened by coastal development, destructive fishing practices, mining runoff, and agricultural pollution. Conservation assessments by the IUCN list several *Hemiscyllium* species as

Vulnerable—*H. galei, H. strahani, H. michaeli, H. henryi,* and *H. hallstromi*—and others as Near Threatened (*H. freycineti* and *H. halmahera*), while only *H. ocellatum* and *H. trispeculare* are categorized as Least Concern and receive protection in Indonesia **(VanderWright *et al.*, 2021; Nakhostin & Dulvy, 2025)**. These classifications reflect ongoing threats, including reef degradation, habitat fragmentation, overcollection for the ornamental fish trade, and destructive fishing practices such as blast and cyanide fishing **(Jutan *et al.*, 2018)**.

Given these challenges, a bibliometric analysis was employed in the current study to assess the current state of *Hemiscyllium* research and its conservation implications. Bibliometric methods allow for a systematic, quantitative assessment of publication volume, collaboration patterns, thematic focus, and citation trends, which are increasingly applied in conservation science to detect research biases, highlight underexplored areas, and guide policy development **(Shu *et al.*, 2024; Li & Zhai, 2025)**. Considering that *Hemiscyllium* spp. face ecological risks, bibliometric insights can help identify research gaps and strengthen evidence-based conservation planning **(Zhao *et al.*, 2024)**. In Indonesia, walking sharks primarily occur in West Papua, Papua, and parts of Maluku, where they inhabit coral reefs, seagrass meadows, and shallow rocky habitats **(Akbar *et al.*, 2023a; Akbar *et al.*, 2025)**. Yet, scientific publications addressing their geographical distribution, habitat conditions, and conservation status remain sparse, underscoring the need for more comprehensive mapping and ecological assessment.

Accordingly, this study presents a bibliometric analysis of global *Hemiscyllium* research, with a focus on species occurring in Indonesia. The objectives were to: (1) map the temporal and thematic distribution of *Hemiscyllium* publications; (2) identify research gaps across geographic, taxonomic, and disciplinary domains; and (3) evaluate how existing studies can inform conservation policy and management frameworks. Based on this analysis, the study recommends expanding field research in key distribution areas, enhancing national and international research collaboration, and integrating scientific findings into adaptive conservation policies to safeguard Indonesia's endemic walking sharks. This aligns with the conclusion of **Akbar *et al.* (2023a)** that existing information is sufficient to inform species-specific conservation policies, and the assertion of **Akbar *et al.* (2025)** that *in-situ* conservation is vital to ensuring long-term species persistence within reef ecosystems.

MATERIALS AND METHODS

Data source and collection procedure

The bibliometric data for this study were obtained from the Scopus database, accessed on 17 February 2025. Scopus was selected due to its comprehensive multidisciplinary coverage of peer-reviewed literature, which minimizes the risk of omitting relevant outputs and ensures diverse representation of scientific publications **(Gorraiz & Schloegl, 2008; Duran-Sanchez *et al.*, 2018)**. The search strategy involved querying

"*Hemiscyllium*" within the title, abstract, and keyword fields, covering journal articles, review papers, and book chapters. A total of 88 documents were retrieved and subjected to bibliometric analysis. This approach was designed to capture the breadth of scholarly discourse on the ecology, taxonomy, physiology, and conservation of *Hemiscyllium* spp., particularly those distributed in Indonesia. All records were downloaded in BibTeX format to facilitate subsequent analysis with specialized software.

Analytical tools and procedures

Two complementary tools were employed:

1. **Biblioshiny (bibliometrix v4.3.0)** – a web-based interface of the R-package *bibliometrix* used for quantitative bibliometric analysis and conceptual mapping **(Zupic & Čater, 2015; Aria & Cuccurullo, 2017)**.
2. **VOSviewer (v1.6.19)** – a Java-based software developed at Leiden University for constructing and visualizing bibliographic networks, including author co-citation maps and keyword co-occurrence networks **(Van Eck & Waltman, 2010; Su *et al.*, 2022)**.

The integration of these tools enabled both descriptive and structural evaluations of the dataset, providing insights into research dynamics, collaboration patterns, and thematic development in *Hemiscyllium* studies.

a. Descriptive bibliometric analysis

The first phase generated descriptive metrics using *Bibliometrix*. Indicators such as annual scientific production, leading authors, most productive institutions and countries, citation counts, influential documents, and journals were extracted. These metrics established a foundational overview of research trends, author productivity, and citation impact, contextualized within global and Indonesian scholarship **(Aria & Cuccurullo, 2017; Singh & Misra, 2021)**.

b. Construction of bibliographic networks

Bibliographic network matrices were produced using the *biblio-network* function to explore relationships among authors, documents, institutions, countries, and keywords. Analyses focused on:

- **Co-authorship networks** – to evaluate collaboration patterns.
- **Co-citation networks** – to identify intellectual foundations.
- **Bibliographic coupling** – to detect thematic similarities across documents.

These approaches revealed structural clusters of researchers and publications contributing to distinct thematic areas **(Kim *et al.*, 2024; Fagang *et al.*, 2025)**.

c. Visualization of bibliographic networks

The *networkPlot* function was applied to visualize networks using algorithms such as Kamada-Kawai, circular layouts, and Multidimensional Scaling (MDS). Visualization enhanced the identification of research hubs, thematic convergence, and underrepresented areas in the scholarly landscape of *Hemiscyllium* spp. research **(Heller *et al.*, 2023; Kim *et al.*, 2024)**.

d. Co-word analysis: Conceptual structure mapping

Co-word analysis examined the conceptual structure of the field by analyzing keyword co-occurrence. Dimensionality reduction techniques, including Correspondence Analysis (CA) and Multiple Correspondence Analysis (MCA), were applied through the *conceptualStructure* function **(Fagang *et al.*, 2025)**. Thematic maps revealed clusters corresponding to coral reef ecology, physiological adaptation to hypoxia, species distribution, and conservation biology. To enrich the dataset, Natural Language Processing (NLP) techniques were used to extract additional terms from abstracts and titles.

e. Historiographic mapping of direct citations

Historiographic mapping was performed using the *histPlot* function to trace the chronological development of *Hemiscyllium* research. Direct citation networks highlighted key turning points, including seminal species descriptions, shifts toward physiological studies, and the more recent emphasis on conservation. This approach captured the intellectual evolution and transformative contributions in the field **(Agbehadji *et al.*, 2023)**.

Ethical considerations and data validity

All data were derived from publicly accessible sources; no human subjects or animal experimentation were involved. Data integrity was ensured through standardized search protocols, metadata cleaning, and duplicate removal. While Scopus provides high-quality coverage, limitations such as language bias and the exclusion of non-indexed local journals are acknowledged. Visual bibliometric analyses are particularly valuable for identifying dominant research clusters, collaboration networks, and the evolution of scientific thought **(Bernardo *et al.*, 2024)**.

RESULTS AND DISCUSSION

Publication performance and trends

A bibliometric analysis of publications on the genus *Hemiscyllium* from 1993 to 2024 identified 88 scientific documents published across 55 sources, including journals, books, and conference proceedings. Over this three-decade period, the average annual growth rate of publications was 3.61%, with an average document age of 13.7 years (Table 1). Although the overall number of publications remains modest, their scientific impact is considerable, with an average of 25.53 citations per document. This suggests that the literature on *Hemiscyllium* has become an important reference point within elasmobranch research and tropical aquatic ecophysiology.

In terms of content, 805 Keywords Plus and 287 Author Keywords were identified, reflecting the breadth of research themes and methodological approaches. Authorship analysis revealed contributions from 250 authors, of whom only four produced single-authored works, totaling just five documents. This demonstrates the highly collaborative

nature of the field. On average, 4.17 authors contributed to each document, and nearly half of the publications (46.59%) were the result of international collaboration, underscoring the presence of a strong global scientific network engaged in *Hemiscyllium* research.

Table 1. Summary of bibliometric data on studies related to the genus *Hemiscyllium* spp.

Description	Results
Main information about data	
a. Timespan	1993:2024
b. Sources (Journals, Books, etc)	55
c. Documents	88
d. Annual Growth Rate %	3.61
e. Document Average Age	13.7
f. Average citations per doc	25.53
g. References	0
Document contents	
a. Keywords Plus (ID)	805
b. Author's Keywords (DE)	287
Authors	
a. Authors	250
b. Authors of single-authored docs	4
Authors collaboration	
a. Single-authored docs	5
b. Co-Authors per Doc	4.17
c. International co-authorships %	46.59
Document types	
a. Article	80
b. Book chapter	1
c. Conference paper	5
d. Review	2

The literature corpus on the genus *Hemiscyllium* demonstrates sustained yet modest growth over a 31-year period (1993–2024). The annual growth rate of 3.61% indicates steady scholarly development, but also reflects the niche character of this field, which contrasts with the rapid expansion observed in broader ecological and conservation research. Despite the relatively small number of publications, the high average citation rate (25.53 citations per document) highlights the academic influence of *Hemiscyllium* studies, particularly in adaptive physiology, coral reef shark ecology, and endemic species conservation.

Collaboration patterns show that the average number of authors per article was 4.17, and nearly half of all publications (46.59%) involved international partnerships. This reflects the multidisciplinary nature of *Hemiscyllium* research and the presence of

robust global collaboration networks. Only five documents were single-authored, reinforcing the dominance of team-based research. In terms of content, 805 Keywords Plus and 287 Author Keywords were identified, pointing to considerable thematic diversity and conceptual richness. These findings suggest scope for deeper exploration of emerging research themes, as illustrated in the thematic map (Fig. 6).

Regarding publication format, journal articles dominated (91% of the total corpus), underscoring that research in this field is primarily disseminated through peer-reviewed scientific outlets rather than books or technical reports. The strategic implications of this observation are threefold:
a) research on *Hemiscyllium* is academically rigorous but remains quantitatively limited;
b) the field is characterized by strong international collaboration and high-quality outputs, providing opportunities for early-career researchers to engage in global networks through locally grounded yet globally relevant conservation themes; and
c) increased contributions from habitat countries such as Indonesia are needed, particularly by fostering greater participation of local researchers in multinational collaborations and developing niche expertise on endemic species such as *H. galei* and *H. halmahera*.

Case studies illustrate the importance of field-based research. **Insani *et al.* (2022)** reported that *H. galei* populations at Doreri Bay are small and highly vulnerable to anthropogenic pressures, especially from coastal ecosystem degradation and settlement expansion. Using the Underwater Visual Census (UVC) method, the study documented low population density and negative allometric growth patterns, both critical indicators for conservation management. Similarly, **Widiarto *et al.* (2020)** monitored *H. freycineti* populations in Misool, Raja Ampat, through snorkel-based visual surveys and shoreline transects. Their findings revealed a population density of 5.29 individuals/ha and a dominance of juveniles, suggesting that the area functions as a natural recruitment ground. Together, these studies emphasize the value of empirical field research as a scientific foundation for species-specific protection policies and sustainable marine conservation strategies in Indonesia.

Growth of publications and citations

The annual trend in publication volume and citation rates related to *Hemiscyllium* from 1993 to 2024 is presented in Fig. (2). During the 1990s, publication activity was sporadic, with only a few papers published, reflecting the limited attention given to the genus at the time. From the early 2000s, publication output increased more consistently, with a notable surge between 2010 and 2015. This rise was likely driven by the discovery of new endemic species in Indonesia, increasing interest in the physiological adaptations of *H. ocellatum*, and growing international concern over elasmobranch conservation.

Since 2015, peaks in publication output have occurred in select years, reflecting heightened interest in the taxonomy, conservation, and physiology of *Hemiscyllium* spp. However, average annual citation counts have declined in recent years—a common

phenomenon attributable to the shorter time frame for newer publications to accumulate citations. In contrast, earlier works from the 2000s continue to show higher citation rates, underscoring their conceptual influence in shaping the field. Thus, Fig. (2) not only reflects the trajectory of research productivity but also highlights the maturation of *Hemiscyllium* studies as an emerging discipline.

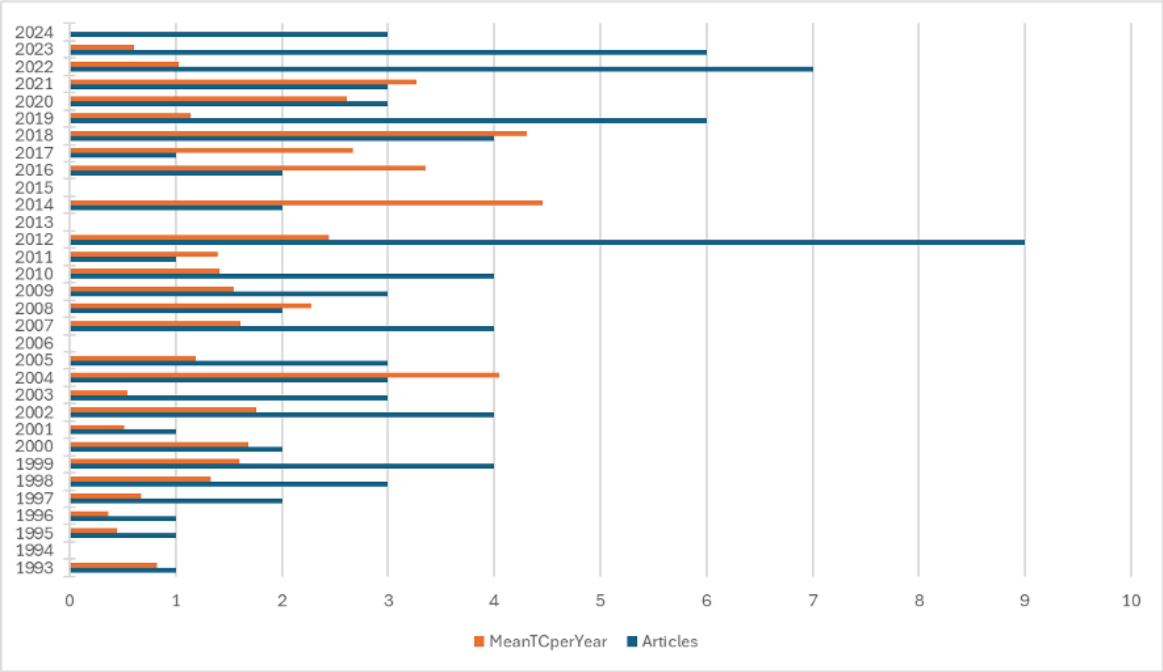

Fig. 1. Annual publication of scientific papers and average citation per year

The publication trends illustrated in Fig. (2) show that research on *Hemiscyllium* has experienced steady, though not rapid, growth, with a clear upward trajectory over the past two decades. This pattern reflects the nature of the field as a niche yet highly relevant research area, particularly in relation to physiological adaptation, endemic species conservation, and elasmobranch biodiversity in the Indo-Pacific region. Overall, Figure 2 suggests that *Hemiscyllium* studies have established a solid academic foundation while retaining substantial potential for future growth—especially if integrated with transdisciplinary approaches and expanded to focus on Southeast Asia's endemic species.

The post-2010 increase in publication output appears to have been driven by growing awareness of marine conservation issues, advances in genetic and physiological methods, and the discovery of new species. Regional and international collaborations have also accelerated this trend. In Indonesia, conservation efforts targeting sharks have gained traction in response to population declines at major landing sites, such as the Fish Auction Center (TPI) Tegalsari, underscoring the need for locally grounded initiatives **(Setiati *et al.*, 2020)**. Previous studies have highlighted sharks' biological vulnerability to overexploitation due to slow growth rates and low fecundity **(Fahmi & Dharmadi,**

2013). For example, *H. freycineti* in Misool was recorded at a density of 5.29 individuals per hectare under conditions of low anthropogenic pressure, emphasizing the role of marine protected areas in conserving habitats of endemic species **(Widiarto *et al.*, 2020)**.

The recent decline in annual citation rates for newer publications represents a common bibliometric pattern, as these works have had limited time to accumulate citations. This trend highlights the need for strategies to enhance scientific visibility, such as publishing in high-impact journals, using strategic keywords, and strengthening international research networks.

Key contributors and publication sources

Table (2) presents the ten most productive authors in *Hemiscyllium* research. The leading contributors are Jodie L. Rummer and Gillian M. C. Renshaw, each with 15 publications. In terms of total citations (TC), however, Renshaw ranks first with 577 citations, followed by Göran E. Nilsson (490 citations). Another entry attributed to Renshaw with 390 citations suggests a duplicate record for the same author, reflecting metadata inconsistencies.

For impact metrics, Renshaw leads with the highest H-index (14), followed by M. B. Bennett and Jodie L. Rummer (both 8). The g-index, which emphasizes highly cited papers, also places Renshaw and Rummer at the top (15 each), indicating several influential publications. Temporal patterns show that senior contributors such as M. B. Bennett and M. R. Heupel have been active since 1996, while more recent authors—including Colin J. Brauner, Anthony P. Farrell, and Anthony J. R. Hickey—entered the field during the 2010s.

These findings demonstrate that *Hemiscyllium* research has attracted attention from scholars across diverse disciplinary backgrounds for more than two decades. The prominence of authors such as Renshaw and Rummer underscores their sustained and influential contributions to this body of literature. Their strong citation indices reflect both productivity and scholarly impact. At the same time, the duplicate entries for Renshaw highlight a common bibliometric challenge—author name variation—which may affect the precision of productivity assessments and requires careful metadata cleaning in future analyses.

Table 2. The top 10 most published authors in the field of '*Hemiscyllium*'

Author	H_index	G_index	TC	NP	PY_start
Renshaw Gillian M. C.	14	15	577	15	1998
Bennett M. B.	8	9	264	9	1996
Rummer Jodie L.	8	15	234	15	2014
Heupel M. R.	7	8	237	8	1996
Nilsson Göran E.	7	7	490	7	1999
Renshaw Gillian M. C.	6	7	390	7	1999
Collin Shaun P.	5	5	202	5	2000
Hickey Anthony J. R.	4	4	205	4	2012

Brauner Colin J.	3	3	186	3	2012
Farrell Anthony P.	3	3	186	3	2012

Note(s): H_index: the H-index identifies the highest number of an author's papers to have the same or higher number of citations; G_index: the G-index attempts to give more weight to highly cited papers; TC: Total citation; NP: number of publications; PY start: Publication year start.

The surge of post-2010 scientific publications reflects both generational renewal and continuity in *Hemiscyllium* research, a trend that is essential for strengthening the scientific foundation of conservation management, particularly in Indonesian waters. Recent scholarship has emphasized the urgency of protecting species with restricted ranges **(Valdor *et al.*, 2020)** and highlighted the value of genomic approaches in understanding population diversity **(King, 2015)**. While international collaborations continue to dominate **(Dulvy *et al.*, 2017)**, increasing the capacity and involvement of local researchers remains critical to ensuring sustainable and locally appropriate conservation outcomes.

Several contributions by Indonesian authors have significantly enriched knowledge on *Hemiscyllium* ecology, distribution, and population biology. These include assessments of population structure and data gaps in Morotai **(Akbar *et al.*, 2023a)**; morphological description and distribution of *H. halmahera* in North Maluku **(Akbar *et al.*, 2019)**; and analyses of species vulnerability to anthropogenic pressures in shallow coral reef ecosystems **(Akbar *et al.*, 2023c)**. Studies of spatial distribution and habitat relationships in Halmahera Bay revealed fragmented distributions, with high densities concentrated in healthy reef habitats **(Arkwright *et al.*, 2025)**. Similarly, investigations into *H. galei* abundance and growth in Doreri Bay demonstrated the localized and fragile nature of its distribution, which is highly susceptible to habitat degradation **(Insani *et al.*, 2022)**. Additional research has documented the ecological role of *H. halmahera* in structuring shallow coral reef communities **(Jutan *et al.*, 2018)** and examined spatial variation in abundance across Halmahera, Maluku **(Mu'min *et al.*, 2021)**. More recently, studies have addressed morphometric aspects and length–weight relationships of *H. halmahera*, reflecting growing attention to species-specific ecological traits **(Akbar *et al.*, 2023b; Akbar *et al.*, 2025)**. Collectively, these works highlight the increasing role of Indonesian scholars in advancing *Hemiscyllium* research and generating evidence-based conservation strategies.

Time-based analysis of author output

The collaborative author network for *Hemiscyllium* research in Indonesia is visualized in Fig. (2). This map illustrates the structure of the scientific community by depicting interconnections among authors through co-authorship links. The visualization reveals a network organized into several distinct clusters, each represented by a different color. These clusters correspond to groups of researchers who collaborate frequently, often reflecting institutional affiliations—for example, the blue cluster dominated by authors from Institution A and the red cluster representing those from Institution B. Such

clustering highlights both the collaborative nature of the field and the emerging influence of regional research hubs within Indonesia's scientific landscape.

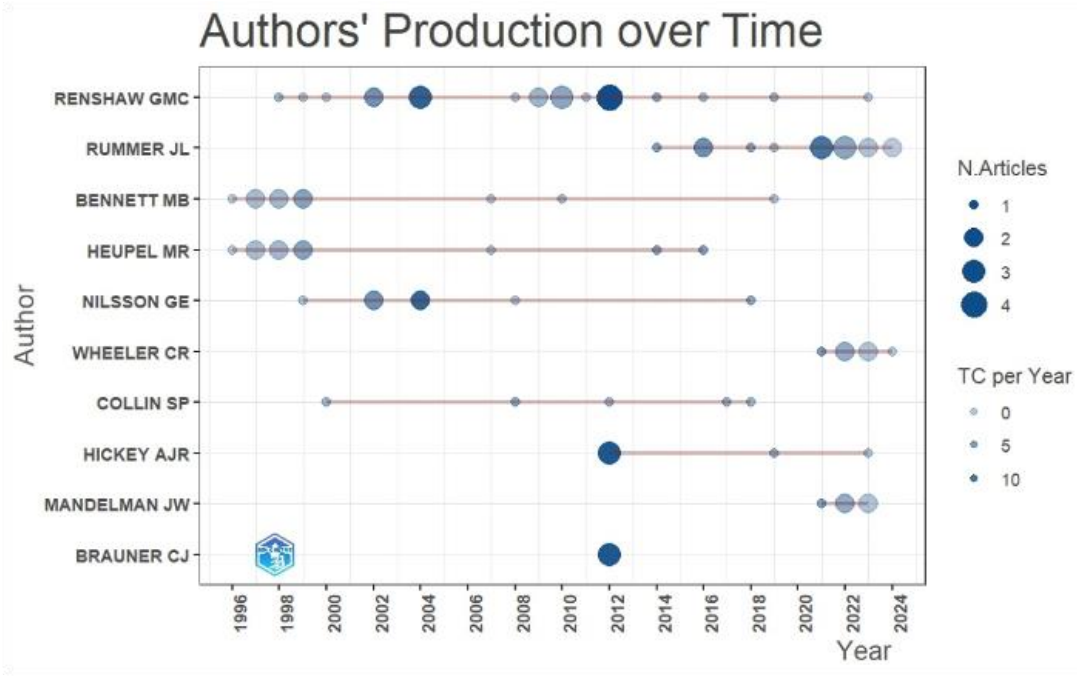

Fig. 2. Annual publication of scientific papers and average citation per author

Several key nodes—most prominently Gillian M. C. Renshaw, Jodie L. Rummer, and Göran E. Nilsson—appear larger than others in the co-authorship network, reflecting their central roles and substantial publication output. The connecting lines (edges) between authors represent co-authored publications, with thicker lines indicating more frequent collaborations. Conversely, the presence of isolated or sparsely connected nodes suggests limited contributions or recent entry into the field.

The network is predominantly shaped by international collaborations, particularly involving researchers from Australia and Europe. Despite Indonesia being the primary geographic focus of many studies, the participation of Indonesian researchers remains limited. This highlights the urgent need to strengthen national research capacity and promote greater involvement of regional scientists in *Hemiscyllium* conservation studies.

The visualization in Fig. (2) further illustrates the social and thematic structures of *Hemiscyllium* research. Distinct clusters within the co-authorship network indicate the presence of research sub-communities, each focusing on themes such as habitat ecology, hypoxia tolerance, and endemic species conservation. For instance, **Renshaw *et al.* (2002)** demonstrated the role of adenosine in the adaptive mechanisms of *H. ocellatum* under anoxic conditions, laying the foundation for subsequent studies on extreme physiological responses.

Prominent nodes such as “Gillian M. C. Renshaw,” “Jodie L. Rummer,” and “Göran E. Nilsson” therefore represent central figures who have shaped active and influential research clusters. If analyzed through a keyword co-occurrence lens, *Hemiscyllium* research would be shown to revolve around several thematic areas, including “endemic shark,” “Papua,” “hypoxia tolerance,” and “coral reef.” The recurrent appearance of “Indonesia” as a bridging keyword underscores the country’s critical ecological role in marine biodiversity research. This aligns with **Mangubhai *et al.* (2012)**, who identified the Bird’s Head Seascape in Papua as a global epicenter of marine biodiversity and a vital habitat for multiple *Hemiscyllium* species, including *H. freycineti, H. galei,* and *H. halmahera*. Strengthening Indonesia’s scientific networks is therefore imperative to ensure greater participation of local researchers in global collaborations and to support the management of endemic species in eastern Indonesian waters.

National contributions and citation averages

The quantitative trends in *Hemiscyllium* research reveal two notable dynamics (Fig. 3). First, in terms of publication volume, there has been a gradual increase since the early 2000s. Prior to 2000, research output was sporadic and limited. A significant surge occurred after 2010, driven by new species discoveries and growing international concern over endemic shark conservation. Recent years show peaks in publication output, reflecting increasing momentum in this research field.

Second, when examining the average number of citations per country, Australia, the United States, and Germany stand out with consistently high citation counts, reflecting their strong scientific influence in global *Hemiscyllium* research. In contrast, mega-biodiverse countries such as Indonesia—despite being home to most *Hemiscyllium* species—exhibit relatively low levels of publication output and citation impact. This disparity underscores the urgent need to strengthen Indonesia’s research capacity, foster equitable participation in international collaborations, and ensure that biodiversity-rich nations contribute proportionately to both scientific knowledge and conservation policy.

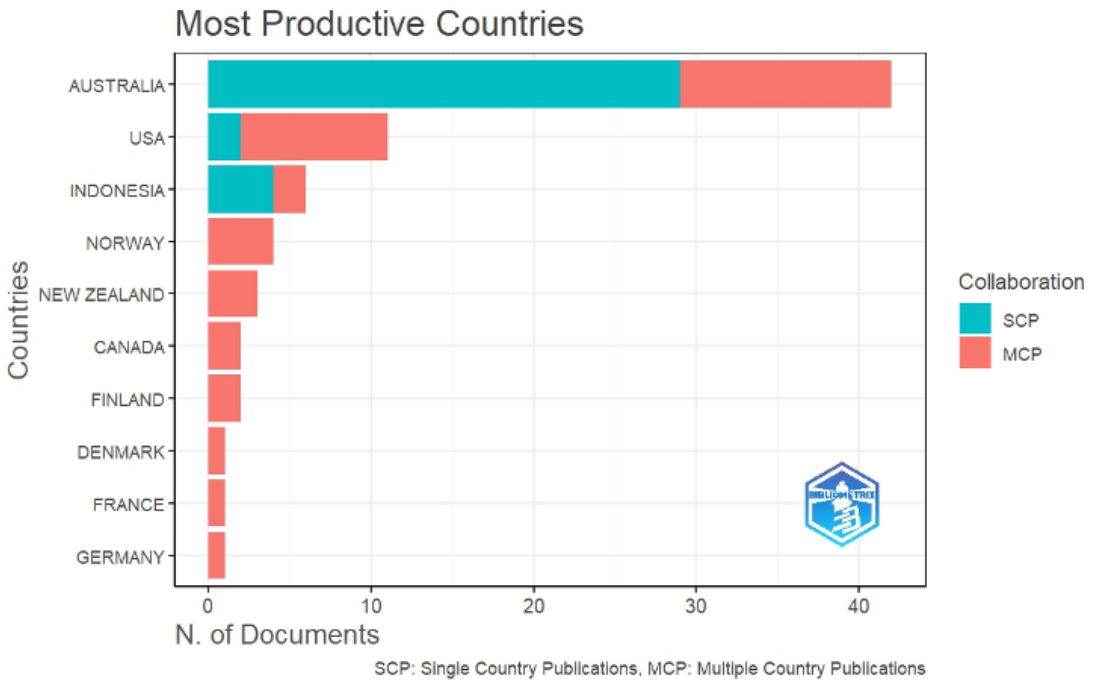

Fig. 3. Annual publication of scientific papers and average citation per country

The disparity in scientific contributions and research impact between countries is clearly illustrated in Fig. (3). Australia, the United States, and Germany occupy the top positions, both in terms of publication volume and average citations per article. This dominance reflects strong research capacity, greater funding availability, and active engagement in international collaborative networks, all of which increase the visibility and impact of *Hemiscyllium* research **(Evans *et al.*, 2021)**.

In contrast, Indonesia—despite being home to several endemic *Hemiscyllium* species, including *H. galei*, *H. halmahera*, and *H. strahani*—recorded relatively low contributions. Our bibliometric dataset shows that Indonesia produced only six publications (6.8% of the total), with an average citation rate of 5.2 citations per paper. This figure is significantly lower than Australia (44 publications, 50.0%; 21.4 citations per paper) and the United States (9 publications, 10.2%; 15.7 citations per paper). This imbalance contrasts with the ecological importance and conservation urgency of Indonesia's *Hemiscyllium* populations. For example, a population study of *H. halmahera* in Morotai Island identified three distinct age cohorts and stable condition factors (0.8169–1.4264), suggesting healthy populations in suitable habitats **(Akbar *et al.*, 2023a)**. Similarly, research on Tawabi Island revealed two main age cohorts, the absence of juveniles, and high condition factors (0.9121–1.1240), indicating that some habitats function primarily as feeding or transitional grounds rather than nursery areas **(Akbar *et al.*, 2025)**. These studies reinforce the ecological value of *Hemiscyllium* while underscoring the disproportionately low number of Indonesian scientific publications relative to the country's biodiversity significance.

The low citation rate of Indonesian outputs may be linked to publication in lower-visibility journals and the limited integration of local researchers into international networks **(Byrd *et al.*, 2011)**. This restricts the influence of regional science on national conservation policies. Addressing this imbalance requires strengthening domestic research capacity and promoting more equitable global collaborations, ensuring that megabiodiverse nations like Indonesia are recognized not only as data providers but also as producers of impactful scientific knowledge **(Clasen *et al.*, 2018)**.

Most productive and influential journals

The most productive and most highly cited journals in *Hemiscyllium* studies are presented in Table (3). Identifying these outlets is critical to understanding the scholarly platforms shaping this research field. Several journals stand out based on two key indicators: the Number of Publications (NP), reflecting productivity, and Total Citations (TC), reflecting impact. Additionally, the h-index provides a balance between quantity and influence, serving as a proxy for journal reputation.

Results show that the *Journal of Fish Biology* is the most productive outlet (NP = 7) but has relatively modest citation impact (TC = 48; h-index = 4). In contrast, the *Journal of Experimental Biology* exhibits the highest citation influence (TC = 416; h-index = 6), making it the most influential publication venue in this domain. Other journals such as the *Journal of Experimental Zoology* and *Comparative Biochemistry and Physiology – A* also report high citation counts despite fewer publications, highlighting their scientific significance.

The majority of articles are concentrated in journals focusing on experimental biology and physiology, reflecting a thematic emphasis on adaptive mechanisms and species biology in *Hemiscyllium* research. Meanwhile, proceedings such as the *IOP Conference Series* show lower citation counts, underscoring their relatively limited impact compared to peer-reviewed journals.

Table 3. The journals with the most publications and the most cited journal by subject

Journal Name	NP	H index	TC
Journal of Experimental Biology	6	6	416
Comparative Biochemistry and Physiology - A Molecular and Integrative Physiology	4	4	129
Conservation Physiology	4	4	96
Journal of Fish Biology	7	4	48
International Journal for Parasitology	3	3	84
Journal of Fish Diseases	3	3	26
Journal of Morphology	3	3	99
Fish Physiology and Biochemistry	2	2	73
IOP Conference Series: Earth and Environmental Science	4	2	6
Journal of Experimental Zoology	2	2	135

The results presented in Table (3) highlight a clear discrepancy between publication frequency and scientific impact (citability) in journals featuring *Hemiscyllium* research. A high volume of published articles does not necessarily equate to greater scientific influence. For example, the *Journal of Fish Biology*, although the most productive outlet, shows relatively low citation metrics. By contrast, journals such as the *Journal of Experimental Biology* and *Comparative Biochemistry and Physiology – A* have fewer articles but exert stronger influence due to their focus on physiological adaptations of walking sharks to extreme conditions, such as hypoxia.

Seminal works illustrate this trend: **Wetherbee and Nichols (2000)** demonstrated the role of adenosine in the survival of *H. ocellatum* under anoxic conditions, while **Boeck *et al.* (2024)** highlighted this species' exceptional hypoxia tolerance, cementing its status as a valuable physiological model. These patterns underscore the strategic importance of publishing in high-impact journals to increase visibility and scholarly influence.

For Indonesian researchers, this represents both a challenge and an opportunity. As argued by **Evans *et al.* (2021)**, increasing the presence of locally relevant research in reputable international journals would not only enhance global recognition of Indonesia's marine biodiversity but also strengthen the integration of national science into conservation policy and international collaborations.

Comparative national publication and citation impact

The annual publication trends on *Hemiscyllium* research by country, shown in Fig. (4), also include the average citation rate per country over time. Australia leads in publication volume, reflecting strong engagement by its researchers and institutions. The United States and Germany also contribute consistently, albeit at lower levels. Since 2010, the number of publications has increased sharply, peaking in several years.

Indonesia shows a modest upward trajectory in output but still lags significantly behind developed countries. Moreover, while average citations per article are high in countries such as Germany and Australia—even with relatively small publication volumes—Indonesia exhibits low citation rates, reflecting limited international visibility and impact. This mismatch between biodiversity significance and research output highlights a critical gap: countries with fewer publications can exert high scientific influence, while higher publication volumes do not necessarily ensure greater impact.

Fig. (4) reinforces earlier findings and emphasizes the need to improve both the quality and visibility of research originating from *Hemiscyllium*'s native habitats. For Indonesia, this means enhancing research rigor, strengthening global collaborations, and targeting high-impact publication venues to ensure that local biodiversity is adequately represented in international conservation discourse.

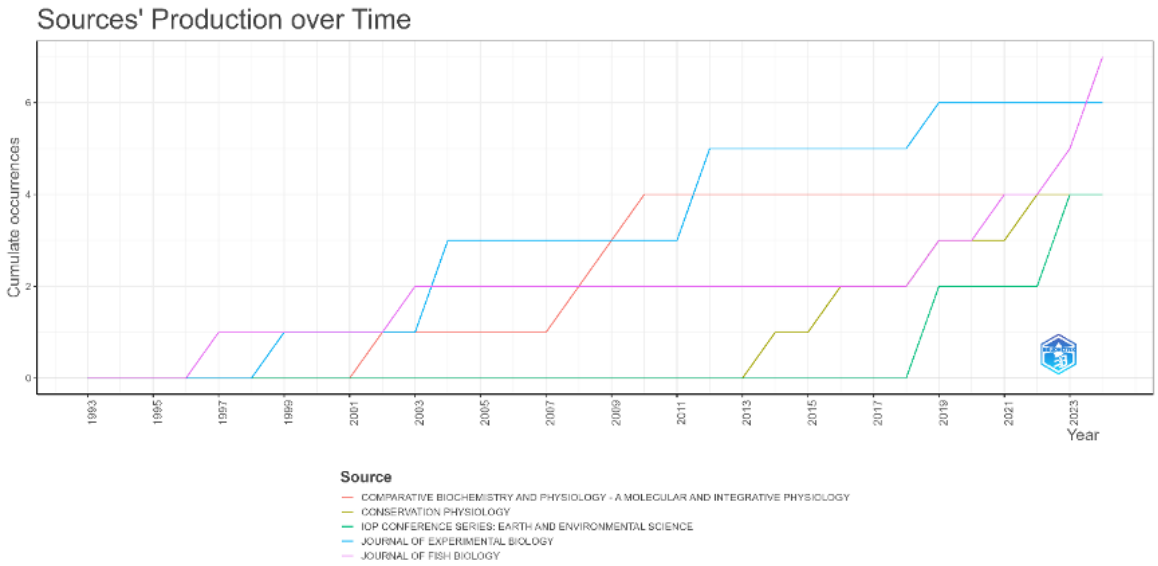

Fig. 4. Annual publication of scientific papers and average citation per countries

The global disparity in *Hemiscyllium* research, as illustrated in Fig. (4), is evident. Although Indonesia represents the primary habitat for several endemic species such as *H. galei* and *H. halmahera* **(Mangubhai *et al.*, 2012; Yong *et al.*, 2016)**, the contribution of Indonesian researchers remains limited in both publication output and citation impact. Several factors contribute to this imbalance, including restricted access to high-impact journals, limited international collaboration, and a lower rate of publications in English.

In contrast, countries such as Australia have leveraged strong research infrastructures, well-established collaborative networks, and access to global publishing systems to produce influential outputs **(Nakhostin & Dulvy, 2025)**. This imbalance underscores the need for biodiversity-rich nations like Indonesia to strengthen their research and publication capacities—not merely as data providers, but as recognized knowledge producers. Enhancing methodological rigor, improving scientific communication skills, expanding training in academic writing, and securing greater support for publishing in reputable international journals are critical steps toward elevating Indonesia's visibility in the global scientific community.

High-impact scientific papers and thematic focus

An analysis of the ten most influential publications in *Hemiscyllium* research (Table 4) highlights both thematic and disciplinary trends, particularly with a strong focus on *H. ocellatum*. The ranking was based on two bibliometric indicators: (a) Total Citations (TC), representing cumulative citations, and (b) Citations per Year (TC/year), which accounts for publication age. Key findings include:

1. **Most Cited Article:** The top-ranked publication is by **Nilsson and Renshaw (2004)** in *The Journal of Experimental Biology*, titled *"Hypoxic survival strategies in two fishes…"*. It has received 224 citations, averaging 10.18 citations

per year. This study compared the extreme hypoxia adaptations of *H. ocellatum* with those of a European freshwater fish.

2. **Dominance of Hypoxia Research:** Seven of the ten most cited articles focus on the physiology of hypoxia tolerance in *H. ocellatum*, demonstrating that metabolic and respiratory adaptations to extreme environments remain the central research theme.
3. **Prominent Authors:** Repeated contributions by Gillian M. C. Renshaw, Göran Nilsson, Anthony Farrell, and Colin Brauner highlight their pivotal roles in advancing knowledge of *Hemiscyllium* physiology.
4. **High-Impact Journals:** These studies were primarily published in prestigious journals such as *The Journal of Experimental Biology*, *Comparative Biochemistry and Physiology*, and *Conservation Physiology*, ensuring broad visibility and citation uptake.
5. **Thematic Expansion:** While hypoxia dominates, other topics such as retinal anatomy and tolerance to elevated CO_2 levels also feature among the high-impact works, signaling diversification into ecological and sensory physiology.

Overall, the most influential literature on *Hemiscyllium* has centered on *H. ocellatum* as a physiological model species. Its unique adaptations to life in shallow lagoons and intertidal zones with fluctuating oxygen levels have established it as a flagship organism in tropical marine ecophysiology. The consistently high citation rates of these works confirm their value not only for species-level understanding but also as reference points for broader fields including evolutionary biology, respiratory physiology, and conservation science.

Table 4. Top ten papers based on total citations

Authors	Article Title	Source	TC	TC per Year
Goran E. Nilsson and Gillian M.C. Renshaw.	Hypoxic survival strategies in two fishes: extreme anoxia tolerance in the North European crucian carp and natural hypoxic preconditioning in a coral-reef shark.	The Journal of Experimental Biology 207, 3131-3139.	224	10.18
Matthew H. Routley, Goran E. Nilsson, and Gillian M.C. Renshaw.	Exposure to hypoxia primes the respiratory and metabolic responses of the epaulette shark to progressive hypoxia.	Comparative Biochemistry and Physiology Part A 131, 313-321 (2022).	98	4.08

Authors	Article Title	Source	TC	TC per Year
M.R. Heupel, J.M. Whittier, and M.B. Bennett.	Plasma Steroid Hormone Profiles and Reproductive Biology of the Epaulette Shark, *Hemiscyllium ocellatum.*	Journal Of Experimental Zoology 284, 586-594 (1999).	76	2.81
Anthony J. R. Hickey, Gillian M.C. Renshaw, Ben Speers-Roesch, Jeffrey G. Richards, Yuxiang Wang, Anthony P. Farrell, and Collin J. Brauner.	A radical approach to beating hypoxia: depressed free radical release from heart fibres of the hypoxia-tolerant epaulette shark (*Hemiscyllum ocellatum*).	J Comp Physiol B 182, 91-100 (2012).	75	5.36
Ben Speers-Roesch, Jefrey G. Richards, Colin J. Brauner, Anthony P. Farrell, Anthony J. R. Hickey, Yuxiang S. Wang, and Gillian M.C. Renshaw.	Hypoxia tolerance in elasmobranchs. I. Critical oxygen tension as a measure of blood oxygen transport during hypoxia exposure.	The Journal of Experimental Biology 215, 93-102.	63	4.50
Lenore Litherland and Shaun P. Collin.	Comparative visual function in elasmobranchs: Spatial arrangement and ecological correlates of photoreceptor and ganglion cell distributions.	Visual Neuroscience, 25, 549-561 (2008).	63	3.50
Anna Bozzano and Shaun P. Collin.	Retinal Ganglion Cell Topography in Elasmobranchs.	Brain Behav Evol, 55, 191-208 (2000).	60	2.31
Max H. Cake, Glen W. Power, Lee M. Stonell, and Ian C. Potter.	Kinetic behaviour of muscle carnitine palmitoyl transferase in the lamprey Geotria australis, before and after.	The Journal of Experimental Zoology, 281, 6-11 (1998).	59	2.11
Gillian M.C. Renshaw, Christopher B. Kerrisk,	The role of adenosine in the anoxic survival of the	Comparative Biochemistry	55	2.29

Authors	Article Title	Source	TC	TC per Year
and Goran E. Nilsson.	epaulette shark, *Hemiscyllium ocellatum.*	and Physiology Part B, 131, 133-141 (2002).		
Dennis D. U. Heinrich, Jodie L. Rummer, Andrea J. Morash, Sue-Ann Watson, Colin A. Simpfendorfer, Michelle R. Heupel, and Philip L. Munday.	A product of its environment: the epaulette shark (*Hemiscyllium ocellatum*) exhibits physiological tolerance to elevated environmental CO_2.	Conservation Physiology, 2 (2014).	55	4.58

Despite the fact that several *Hemiscyllium* species—*H. galei, H. halmahera, H. freycineti,* and *H. strahani*—are endemic to Indonesian waters **(Allen & Erdmann, 2008; Allen *et al.,* 2013; Akbar *et al.*, 2019; Mu'min *et al.,* 2021; Tapilatu *et al.*, 2022; Akbar *et al.,* 2023a; Galitan *et al.,* 2023)**, the contribution of Indonesian scientists to the literature remains limited. For instance, a bioecological study in Doreri Bay by **Insani *et al.* (2022)** documented the habitat characteristics and behavior of *H. galei*, yet such field-based publications remain scarce. Similarly, **Arkwright *et al.* (2025)** investigated the spatial distribution of *H. halmahera*, but the research was primarily led by foreign collaborators. Although much of the biological data originates from Indonesia, most publications are still dominated by institutions based in Australia and Europe.

This imbalance underscores the urgent need to strengthen Indonesia's national research capacity. Key priorities include advancing physiological research on local species, providing international training in scientific writing, and fostering more equitable research collaborations. Future research should move beyond species inventories and toward understanding adaptation mechanisms, thereby contributing to the development of species-specific conservation physiology models.

Core thinkers and thematic groupings

The author co-citation network in *Hemiscyllium* research, visualized in Figure 5 using VOSviewer, illustrates the intellectual structure of the field. In this network, each node represents an author, with connecting lines indicating the frequency of co-citation. Larger nodes represent higher co-citation intensity, while the density of connecting lines reflects an author's level of integration into the broader research community.

Gillian M. C. Renshaw emerges as the most dominant figure, frequently co-cited with others and serving as a central node in the network. Other influential scholars

include Jodie L. Rummer, Göran E. Nilsson, and M. B. Bennett. The network also reveals several distinct intellectual clusters, represented by different colors:

- **Hypoxia physiology** – led by Renshaw, Nilsson, and Rummer.
- **Reproduction and endocrinology** – represented by Heupel and Bennett.
- **Visual anatomy and morphology** – represented by Collin and Bozzano.

The proximity of nodes within each cluster indicates strong thematic connections, whereas isolated nodes point to narrower specializations or emerging subfields. Together, these clusters map the intellectual landscape of *Hemiscyllium* studies, showing how research has coalesced around specific themes while leaving room for broader integration across disciplines.

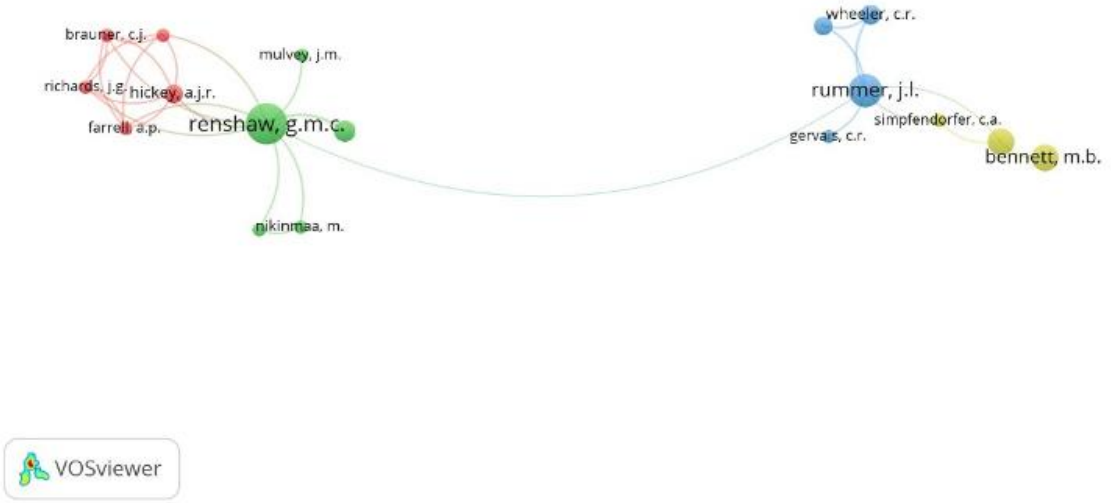

Fig. 5. Author co-citation network

The intellectual structure of *Hemiscyllium* research, as illustrated in Fig. (5), demonstrates how authors and ideas are interconnected within a global scholarly network. Co-citation analysis not only identifies key conceptual anchors but also reveals the evolution of methodological approaches within the field. Among them, Gillian M. C. Renshaw stands out as the most influential figure, particularly in studies of *H. ocellatum* and its hypoxia adaptation mechanisms, as her work is consistently co-cited with other leading scholars.

The network delineates several thematic clusters, with physiology emerging as the dominant field, followed by biochemistry, morphology, and behavioral ecology. Representative studies include:

- **Chapman *et al.* (2010)** – explored anoxia tolerance in *H. ocellatum*.
- **Devaux *et al.* (2023)** – investigated succinate-mediated ROS production in the species.
- **Gauthier *et al.* (2018)** – compared electrosensory systems of *H. ocellatum* and *C. punctatum*.

- **Heinrich *et al.* (2016)** – assessed foraging behavior of *H. ocellatum* under elevated CO_2 conditions.

These patterns suggest that the citation structure functions as a knowledge hierarchy, with a small group of authors acting as conceptual hubs for subsequent research. For Indonesian scientists, gaining greater recognition requires strategically targeting these thematic areas and prioritizing publication in high-impact international journals. Moreover, mapping intellectual clusters provides a practical framework for building collaborative linkages with leading scholars, thereby expanding local researchers' integration into the global knowledge network.

Author productivity and citation impact

Bibliometric analysis of *Hemiscyllium* research identifies the top nine contributing authors, based on both publication output and total citations (Table 5). These indicators serve as benchmarks of productivity and scholarly influence within the field.

- Gillian M. C. Renshaw leads the list, with 22 publications and 967 citations, firmly establishing her as a central authority in *Hemiscyllium* studies.
- Jodie L. Rummer (15 publications, 234 citations) and Göran E. Nilsson (7 publications, 490 citations) also hold pivotal positions, particularly due to their high average citations per article, reflecting the depth of their conceptual contributions.
- Bennett M. B. and M. R. Heupel display a balance of productivity and influence, bridging physiology and ecological perspectives.
- Carolyn R. Wheeler and John W. Mandelman represent more recent entrants into the field, with moderate output but relatively low citation counts—suggesting emerging but not yet fully established influence.
- In contrast, Anthony Jr. Hickey, with only four publications but 205 citations, demonstrates the capacity for high impact within specialized areas, particularly hypoxia physiology.

Collectively, these findings illustrate a hierarchical structure of expertise, dominated by a few prolific authors but enriched by newer contributors diversifying the field's thematic scope. For researchers from megabiodiverse regions such as Indonesia, aligning with these core thinkers through targeted collaboration and joint publications, this offers a strategic pathway to elevate both visibility and impact within the global *Hemiscyllium* research community.

Table 5. Top authors based on the number of documents and citations

Author	Documents	Citations
Renshaw Gillian M. C.	22	967
Rummer Jodie L.	15	234
Bennett M. B.	9	264

Heupel M. R.	8	237
Nilsson Göran E.	7	490
Wheeler Carolyn R.	6	40
Collin Shaun P.	5	202
Mandelman John W.	5	40
Hickey Anthony J. R.	4	205

Table (5) underscores the dominance of a small number of authors within the *Hemiscyllium* research community, reflecting an elite knowledge structure shaped by a few highly productive and influential scholars. This concentration of expertise indicates that only a handful of authors are both quantitatively prolific and qualitatively impactful, thereby exerting substantial influence on the field's intellectual trajectory.

Among them, Gillian M. C. Renshaw exemplifies a core author, with foundational contributions to studies on hypoxia adaptation in *H. ocellatum* **(Chapman *et al.*, 2010)**. Her central position in the author co-citation network (Fig. 5) confirms her role as a pivotal reference point for subsequent research. Similarly, Göran E. Nilsson, despite publishing fewer papers, has produced highly cited work on oxidative stress and reactive oxygen species (ROS) production under anoxic conditions **(Devaux *et al.*, 2023)**, positioning him as another conceptual anchor.

Other influential contributors include **Gauthier *et al.* (2018)**, who advanced comparative anatomical knowledge through analyses of the electrosensory system. While **Heinrich *et al.* (2016)** examined behavioral ecology by evaluating foraging responses of *H. ocellatum* under elevated CO_2 conditions. Together, these studies illustrate how physiology, anatomy, and behavioral ecology form interlinked thematic pillars within *Hemiscyllium* research.

In contrast, authors such as Carolyn R. Wheeler and John W. Mandelman appear as emerging contributors. Their lower citation counts may reflect their focus on subthemes not yet dominant within the field or their relatively recent entry into the research domain. For researchers in megabiodiverse countries such as Indonesia, strategic collaboration with core authors like Renshaw, Nilsson, and Rummer offers a practical pathway into global research networks—where expertise, rather than geography, defines intellectual influence.

Thematic mapping through keyword co-occurrence analysis

The keyword co-occurrence network presented in Fig. (6) provides a conceptual overview of dominant research themes in *Hemiscyllium* studies. Generated using VOSviewer, this visualization reveals how keywords cluster into thematic areas while highlighting the most influential concepts.

Central nodes such as "Hemiscyllium ocellatum," "hypoxia," "epaulette shark," "oxygen," and "physiology" dominate the map, confirming the strong emphasis on physiological research. Meanwhile, geographically specific terms like "Indonesia" and "endemic species" appear as smaller nodes, suggesting ecological and regional relevance but limited conceptual prominence within the broader literature.

The network is divided into color-coded clusters, each representing distinct thematic orientations:

- **Red cluster** – focused on hypoxia adaptation and metabolic responses, with keywords like "anaerobic metabolism" and "oxygen consumption."
- **Blue cluster** – emphasizing habitat ecology and distribution, linking terms such as "reef," "coral," and "Papua."
- **Green cluster** – oriented toward genetics, conservation, and biodiversity, with keywords like "population structure," "genetics," and "conservation biology."

Notably, bridging terms such as *"climate change," "ocean acidification," and "metabolism"* link otherwise distinct clusters, reflecting the emergence of transdisciplinary perspectives that integrate physiology, ecology, and conservation. This structural mapping highlights the maturation of *Hemiscyllium* research from narrowly focused physiological studies to a more integrated field addressing both fundamental biology and applied conservation challenges.

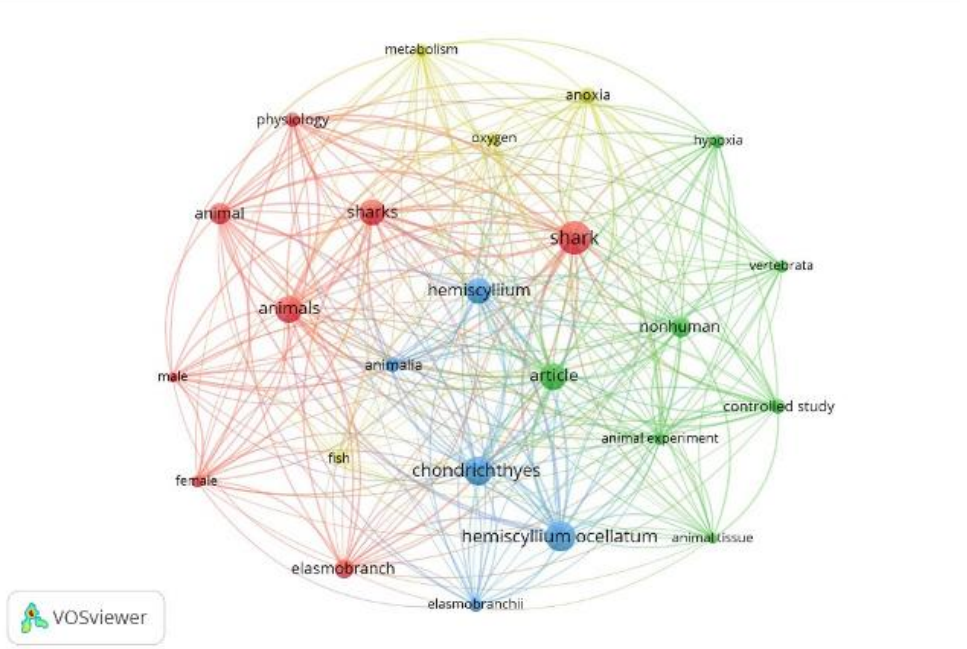

Fig. 6. Co-occurrence network of the most frequently used keywords

The visualization in Fig. (6) illustrates the conceptual structure of *Hemiscyllium* research, showing a clear dominance of studies on adaptive physiology under hypoxic conditions, particularly in *H. ocellatum*. Central keywords such as *"hypoxia," "tolerance,"* and *"oxygen"* underscore the strong scientific interest in this species' ability to survive in low-oxygen reef and intertidal environments.

At the same time, the emergence of terms like *"Indonesia"* and *"endemic species"* signals growing recognition of the genus' restricted geographic distribution, though these remain secondary nodes compared to physiological themes. Importantly, the map highlights an increasingly multidisciplinary trajectory, with newer terms reflecting integration of:

- **Molecular biology** (*"gene expression"*),
- **Climate change biology** (*"acidification," "climate change"*), and
- **Habitat conservation** (*"reef," "distribution," "endangered species"*).

For example, **Heinrich *et al.* (2014)** demonstrated physiological tolerance of *H. ocellatum* to elevated CO_2, a finding relevant under ocean acidification scenarios, while **Wheeler *et al.* (2022)** showed that upper thermal tolerance in *H. ocellatum* is unaffected by sex, life stage, or body size, suggesting adaptive potential under ocean warming. In a conservation context, **VanderWright *et al.* (2021)** assessed extinction risks in small-population species such as *H. halmahera*, which faces heightened vulnerability due to its restricted distribution in Indonesian waters. Complementary to this, **Madduppa *et al.* (2020)** employed morphometric and DNA barcoding methods to identify *H. halmahera*, improving understanding of its population boundaries and conservation needs. Similarly, **Johnson *et al.* (2016)** evaluated the effects of ocean acidification on early ontogeny in *H. ocellatum*, highlighting developmental vulnerabilities under changing ocean chemistry.

The implications of this thematic mapping are threefold:

1. **Research Gap Identification** – The relatively weak representation of terms related to *genetics*, *population dynamics*, and *community-based conservation* indicates opportunities for future inquiry.
2. **Strategic Publishing** – Positioning articles within dominant clusters and using high-frequency keywords can improve visibility and citation performance.
3. **Indonesian Contribution** – By strengthening studies centered on keywords like *"Indonesia"* and *"endemic"* while linking them to global issues such as climate resilience and physiological adaptation, Indonesian researchers can raise both scientific relevance and policy impact.

CONCLUSION

This bibliometric analysis of *Hemiscyllium* research (1993–2024) demonstrates a field characterized by steady growth yet high scientific influence, with an average of 25.53 citations per document and nearly half of all publications (46.59%) involving international collaboration. Despite being the primary habitat for several endemic

species—such as *H. galei* and *H. halmahera*—Indonesia remains underrepresented, contributing only 6.8% of publications and with comparatively low citation impact.

The research landscape is heavily skewed toward physiological adaptation studies, particularly hypoxia tolerance in *H. ocellatum*, largely shaped by a small circle of influential international researchers. This pattern reflects both the strengths and limitations of the current knowledge base: while physiological insights have positioned *Hemiscyllium* as a model organism in marine ecophysiology, broader ecological, genetic, and conservation dimensions remain underexplored.

To close this gap, several strategic priorities emerge:

1. Strengthening national research capacity – enhancing Indonesian contributions through training in scientific writing, methodological rigor, and publication in reputable international journals.
2. Expanding thematic scope – integrating genomics, ecology, and resilience frameworks to complement physiological research and build holistic conservation strategies.
3. Fostering equitable collaboration – moving beyond data provision to ensure Indonesian researchers act as producers of globally recognized scientific knowledge.
4. Linking science to conservation policy – positioning *Hemiscyllium* spp. as flagship taxa for tropical marine conservation, embedded within transdisciplinary frameworks that connect science, policy, and community-based stewardship.

In doing so, research on *Hemiscyllium* can transition from a niche field dominated by physiological studies into a comprehensive conservation science agenda, ensuring the long-term survival of these ecologically unique and geographically restricted shark species.

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