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A COMPREHENSIVE BIBLIOMETRIC ANALYSIS OF OTOLITH RESEARCH ON EELS

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Abstract

Otoliths serve as biogenic archives that reveal age, growth, habitat shifts, and environmental histories of fishes. We analyzed 94 years of eel otolith research (374 Scopus-indexed papers, 1930–2023) and visualized co-authorship and keyword networks with VOSviewer. Output rose sharply after 2000, dominated by Japan (26%), Taiwan (12%), and France (11%), forming dense clusters of collaboration among Japan, Taiwan, France, and North America. Research themes progressed from early age and growth studies to otolith microchemistry, migration and recruitment dynamics, and, more recently, to conservation, contaminants, and climate change. Core keywords (“otolith,” “age,” “growth,” “migration”) persist, with newer emphases on phenotypic plasticity and restoration. Tropical anguillids remain underrepresented relative to temperate species, non-anguillid eels appear sporadically, and several life stages—especially leptocephali and yellow eels—are unevenly studied. This synthesis benchmarks global eel otolith scholarship and identifies priorities for cross-regional collaboration and conservation-linked research.

Keywords: *Anguilla*, eels, otolith, microchemistry, Scopus, VOSviewer

Introduction

Otoliths are calcium carbonate structures in the teleost inner ear that are involved in balance and hearing, and they contain a finely resolved archive of growth and environmental conditions.

Their accretional chemistry and microstructure integrate temperature, salinity, and physiological state, enabling age and growth estimation and retrospective reconstruction of habitat use and movement (Arai 2022, Arai *et al.* 2017,

Campana 1999, Podda *et al.* 2023, Kern *et al.* 2017). Among eels, otolith analyses have illuminated ageing, migration, and life-history diversity across larval leptocephalus, glass eel, elver, yellow, and silver stages (Durif *et al.* 2020, Kita *et al.* 2020, Silm *et al.* 2017, Arai *et al.* 2018, 2020, Arai & Chino 2022a, Kuroki *et al.* 2014, Lin *et al.* 2015, Arai *et al.* 2017, Milošević *et al.* 2021). Anguillid eels undertake long marine spawning migrations and support culturally and economically important fisheries in East and Southeast Asia and beyond (Osmaleli *et al.* 2023, Williamson *et al.* 2023, Han *et al.* 2019, Kaifu *et al.* 2014). Yet populations have declined under the combined pressures of overexploitation, habitat modification, barriers, pollution, and climate variability, prompting protective measures and intensifying the need for robust life-history evidence to guide conservation (Denis *et al.* 2022, Durif *et al.* 2023, Han *et al.* 2019, Kaifu *et al.* 2014, 2018, Otake *et al.* 2019, Rohtla *et al.* 2021, Shirai *et al.* 2018).

Prior syntheses have reviewed otolith methods and eel biology but have not mapped how the field itself has evolved through time (McCleave 2008, Starrs *et al.* 2014, Durif *et al.* 2023). Bibliometric analysis offers that lens: by quantifying publication and citation dynamics, collaboration networks, and co-occurring keywords, it reveals the discipline's intellectual structure and emergent fronts (Ilmasari *et al.* 2022, Sahabudin *et al.* 2024). Because “eel” is used broadly in the literature, we clarify the scope. Our analysis centres on anguillid eels, while acknowledging relevant otolith studies on marine eels in Congridae and others where they intersect with migration and life-history inference (e.g., *Conger conger*, *C. myriaster*) (Matić-Skoko *et al.* 2012, Bae *et al.* 2018, Mu *et al.* 2018, 2021, 2022). We also situate this work alongside regional otolith bibliographies that span multiple fish taxa, including Southeast Asia's growing use of otoliths for research (Calizo *et al.* 2023). Here we compile Scopus-indexed eel-otolith publications (1930–2023) and apply standard bibliometric and network visualizations to: 1) quantify temporal growth & geographical distribution of research; 2) identify leading journals, institutions, and authors; 3) map international co-authorship; and 4) track thematic evolution using keyword co-occurrence. We use these patterns to highlight persistent knowledge gaps and conservation-relevant opportunities at the intersection of otolith science, eel life histories, and environmental change.

Materials and methods

Data collection and search strategy. We retrieved bibliometric records from Scopus on 22 July 2024 using the query TITLE-ABS (otolith) AND TITLE-ABS-KEY (eel OR elver), restricted to journal articles published from 1930 to 2023 (Source type: journals; Document type: articles). The initial search returned 388 records. We then excluded reviews and bibliometric papers with an additional filter (AND NOT review and AND NOT bibliometric), yielding 383 research articles. Titles and abstracts were screened to retain studies explicitly addressing eel otoliths, resulting in a final dataset of 374 articles. The complete dataset was exported in CSV format with citation details, bibliographic information, abstracts, author keywords, and related metadata. The workflow is summarized in Sup. Fig. 1. Scope was not limited taxonomically: studies on anguillid eels and other eel taxa (e.g., congrid and moray eels) were eligible if otoliths were a primary focus.

Data processing and bibliometric mapping. We computed annual publication output and productivity by country, institution, author, journal, and subject area in Microsoft Excel 365. Network analyses were conducted in VOSviewer v1.6.18. We generated two maps: (1) country co-authorship and (2) author-keyword co-occurrence. For the co-authorship map, countries with at least three publications were included (27 countries met the threshold). Link strength represents the number of jointly authored publications between country pairs; node size reflects publication volume. For the keyword analysis, author keywords were standardized using a synonym list (e.g., “otoliths,” “otolith microchemistry,” “otolith microstructure,” “otolith Sr:Ca ratio” consolidated as “otolith”). A minimum co-occurrence of three was applied, producing a network of 90 keywords. We used overlay visualization to display the average publication year of keywords and examined thematic evolution across four non-overlapping time slices: 1930–2000, 2001–2008, 2009–2016, and 2017–2023. Visualization conventions followed VOSviewer defaults: node diameter denotes prominence, inter-node distance indicates association strength, and thicker edges reflect greater link strength.

Results

Scope of the bibliometric dataset. Unless otherwise noted, “eels” refers to anguillid eels (*Anguilla* spp.), which dominate the dataset. A

smaller subset of records concerns conger eels (Congridae) and, rarely, morays (Muraenidae) and ophichthids; this breadth is visible in the keyword networks where *Conger conger* and *C. myriaster* appear at low frequency.

Trends in otolith publications. After sporadic publications in the 1930s and a long hiatus until 1962, output remained low through the 1970s, rose modestly in the 1980s, then doubled from 2000–2010. Over the last 13 years, publication volume stabilized at roughly 15 papers annually despite the COVID-19 period (Fig. 1). The topic has been addressed in 42 countries; Japan leads with 26.2% of papers, followed by Taiwan (11.5%) and France (10.7%), with the United States and Canada each contributing 6.4%. New Zealand and Germany contribute ~4% each, Italy and Portugal ~2.9% each, and China 2.4%.

Most productive journals. Across 107 journals, publication is highly skewed: 81.3% of outlets published fewer than 10 papers. The Journal of Fish Biology ranks first (43 papers, 11.5%), followed by Marine Ecology Progress Series (30, 8%) and Marine Biology (26, 6.9%). Marine Ecology Progress Series leads in citations (2436), ahead of Marine Biology (1184). Among the top 10 outlets, Estuarine, Coastal and Shelf Science has the highest 2023 CiteScore (5.6) despite only nine papers (Table 1). Six publishers appear in the top 10, with Springer Nature contributing three journals.

Subject areas. Sixteen subject areas are represented, dominated by Agricultural and Biological Sciences (332 papers). Environmental Sciences (127) and Earth and Planetary Sciences (58) follow, with smaller contributions from Biochemistry/Genetics/Molecular Biology (11) and Multidisciplinary (8). The share of Agricultural and Biological Sciences exceeded 50% each decade, peaking in the 1990s (64.3%) and declining to 51.9% in the 2020s. Environmental Sciences peaked in the 2000s (27.8%), while Earth and Planetary Sciences grew to 15.6% in the 2020s (Sup. Fig. 2).

Institutions. One hundred and sixty institutions contributed, including 107 academic organizations (non-academic agencies excluded). The University of Tokyo leads with 96 papers (25.67%), followed by National Taiwan University (58, 15.5%). Academia Sinica (Taiwan) and its Institute of Earth Sciences contributed 32 and 31 papers, respectively. Université de Perpignan Via Domitia (France) produced 18 papers; the Institute of Freshwater Research (China), Kyushu University (Japan), and Bedford Institute of Oceanography (Canada) each produced 13; the Institute of Oceanography, NTU (Taiwan), 13; and University of Porto (Portugal) 11 (Sup. Table 2). Average citations per paper are highest for the University of Tokyo (103), followed by National Taiwan University (77.3), Academia Sinica (67.8), and IES (66.9).

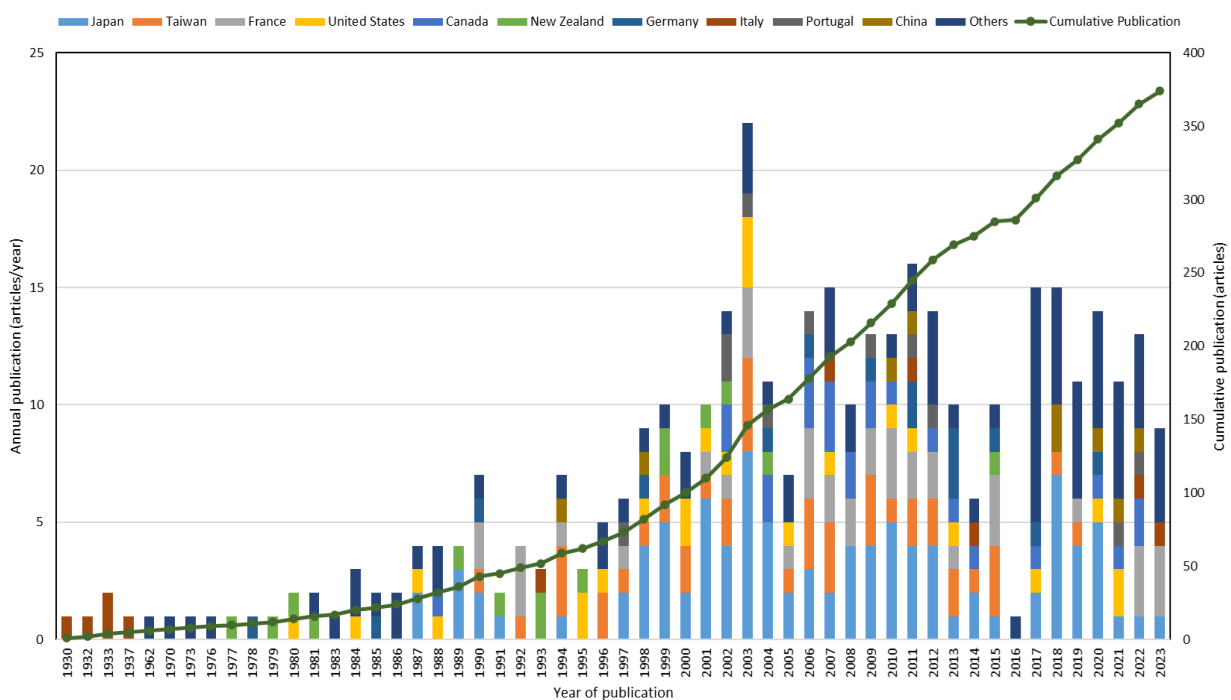


Figure 1. Annual publications on eel–otolith research, 1930–2023. The dots and line are cumulative publications

Authors. The most prolific authors over 94 years are largely based in Japan and Taiwan (Sup. Table 3). Tsukamoto, K. leads (62 papers; author h-index 65), followed by Tzeng, W.N. (50, h-index 39) and Arai, T. (48, h-index 39). Jessop, B.M., is the only non-Asian author among the top 10. The clustering of five University of Tokyo-affiliated authors underlines that institution's centrality. In Taiwan, National Taiwan University and Academia Sinica anchor productivity.

International collaboration. Co-authorship mapping identifies 31 collaborating countries across Asia (9), Europe (14), the Americas (3), Africa (1), and Oceania (2) (Sup. Fig. 3). Japan is the principal hub, collaborating with 18 countries and co-authoring 116 papers. Its strongest links are with Taiwan (58 papers), France (50), the United States (39), Canada (34), Germany (22), and New Zealand (20), with additional ties to Indonesia (10), Brunei Darussalam (9), Malaysia (5), and Vietnam (3). Taiwan places second (58 multi-country papers, 15 partner countries), and France third (50 papers, 15 partners), including ties to Indonesia. Strong Japan–France and France–Canada links are evident.

Keyword structure. From 683 author keywords, data cleaning, and a ≥ 3 -occurrence threshold we derived 90 terms (Sup. Fig. 4). “Otolith” is the central term (143 occurrences; 50 links). “Growth” (55, 40 links), “migration” (47), and “age” (41, 31 links) form the main conceptual axis, connecting life-stage terms (leptocephalus, glass eel, elver, yellow eel, silver eel). Species terms are frequent for *Anguilla japonica* (48), *A. anguilla* (46), *A. rostrata* (17), *A. australis* (10), *A. dieffenbachii* (8), *A. marmorata* (7), with lower counts for *Conger conger* (7) and *Conger myriaster* (3). “Sr:Ca ratio” (24, 22 links) connects strongly with “migration,” “salinity,” and “environmental history,” reflecting the use of otolith microchemistry in habitat reconstruction. Conservation-adjacent terms occur at low but rising frequency: “endangered species” (3, 9 links), “conservation,” “stocking,” “stable isotope,” “spawning,” and “LA-ICPMS.”

Temporal evolution of topics (1930–2023). We divided publications into four periods to track topic shifts.

- **1930–2000:** A phase of limited research with 15 keywords. Work centered on age, growth, and early life stages, especially elvers, and on a narrow set of species (*A. dieffenbachii*, *A. australis*, *A. anguilla*, *A. japonica*).

Temperature and strontium emerged as early process-oriented terms.

- **2001–2008:** Rapid expansion. New terms included habitat, life history, Sr:Ca ratio, recruitment, reproduction, and environmental history. *A. marmorata* and *A. rostrata* entered the record; attention to leptocephalus and glass eel stages increased, and otolith chemistry became a mainstream tool for reconstructing catadromous movements across marine, estuarine, and freshwater habitats.
- **2009–2016:** Geographic and thematic broadening. Tropical eels, especially *A. marmorata*, gained prominence; “stocking” and “distribution” appeared; studies began addressing ecological risk alongside migration and growth. Silver-eel life stage and management linkages strengthened.
- **2017–2023:** Consolidation around conservation. The vocabulary contracted but added “conservation,” “spawning,” “dispersal,” and “phenotypic plasticity,” reflecting endangered listings and management needs. Research continued to emphasize *A. anguilla* and *A. japonica* while retaining coverage of early life stages and temperature-linked growth dynamics.

Notes on taxonomic breadth and visualization. The keyword network confirms that most studies address the Anguillidae, with fewer papers on Congridae and sporadic references to morays and ophichthids, aligning with the search strategy and field focus. Figure 1, Sup. Figures 1–4, and Sup. Tables 1–3 summarize volume, venues, institutional and author productivity, collaboration structure, and the thematic landscape over time.

Discussion

Global publication dynamics and collaboration.

Eel-otolith research expanded steadily after the year 2000 and remained resilient through the COVID-19 years, with mean annual output rising from roughly one paper per year pre-1980 to about 15 per year in the last decade (Fig. 1). Japan dominates the field by volume, authorship, and network centrality, partnering with 18 countries and producing the most collaborative publications; Taiwan is consistently second. These leadership patterns mirror the species' commercial importance in East Asia and a long-standing institutional focus in both countries (Sup. Fig. 3). Co-authorship mapping reinforces

the centrality of Japan–Taiwan–France links and shows ties spanning all five continents, with especially strong Japan–Taiwan (58 papers) and Japan–France (50) axes that anchor the global network (Sup. Fig. 3). National share patterns in the results underscore this picture: Japan accounts for ~26.2% of all publications, followed by Taiwan (11.5%) and France (10.7%); the United States and Canada each contribute ~6.4% (Fig. 1). Institutionally, output is concentrated in a few hubs led by the University of Tokyo and National Taiwan University, with Academia Sinica also prominent; average citation rates vary widely across institutions, reminding us that productivity and impact are not interchangeable. High-cost research systems contribute disproportionately to highly cited work, but the expanding Southeast Asian participation indicates a diversifying base of expertise that can enrich comparative and tropical perspectives.

Journals, subject areas, and access. Most papers appear in fisheries and marine journals; the *Journal of Fish Biology* is the most productive outlet, while *Marine Ecology Progress Series* leads in citations. Estuarine, Coastal and Shelf Science carries the highest recent CiteScore among the top outlets despite lower volume, illustrating that journal impact and topic productivity need not align (Sup. Table 1). Across decades, Agricultural and Biological Sciences remain the primary subject area, with Environmental Science peaking in the 2000s and Earth and Planetary Sciences growing in the 2020s (Sup. Fig. 2). English overwhelmingly dominates the literature and only one-third of papers are open access, even though several of the most cited eel–otolith articles are openly available, a pattern consistent with increased visibility due to open access.

Conceptual focus and species coverage. Keyword structure centres on “otolith,” tightly coupled with “growth,” “age,” and “eel,” reflecting the method’s core applications in ageing, growth back-calculation, and life-history reconstruction. The network also links these themes to life-stage terminology from leptocephalus to silver eel and to movement terms such as “migration,” “catadromous,” and “recruitment,” consistent with otoliths’ value for inferring environmental transitions (Sup. Fig. 4). Data processing choices that merged synonymous terms prior to mapping and set a minimum co-occurrence threshold of three helped consolidate a robust, interpretable network from 683 raw keywords (reduced to 90).

Sr:Ca profiles occupy a pivotal place in the network and the narrative of the field: peaks near the core reflect marine larval phases, while sub-core trajectories separate lifetime histories of sea, estuarine, and freshwater residence. Published thresholds widely used in eel studies distinguish sea residents ($\text{Sr:Ca} \geq 6.0 \times 10^{-3}$), estuarine shifters ($2.5\text{--}6.0 \times 10^{-3}$), and freshwater residents ($< 2.5 \times 10^{-3}$), operationalizing habitat reconstruction at individual and population scales.

Temporal shifts in emphasis. The overlay analysis clarifies a four-phase evolution. Early work to 2000 concentrated on ageing and growth and established microstructural reading at elver and glass-eel stages. The 2001–2008 period broadened to migration and habitat use, with Sr:Ca analysis standardizing reconstructions across *A. japonica*, *A. rostrata*, *A. australis*, and *A. dieffenbachii*. From 2009–2016, the focus expanded to tropical taxa, especially *A. marmorata*, and introduced management-linked terms such as stocking and distribution; the literature also began treating ecological risk, including pollutant burdens that covary with time in marine or fresh waters. Since 2017, research has increasingly emphasized conservation, spawning, and phenotypic plasticity, topics now occupying newer areas of the keyword network. This shift marks a transition from descriptive studies of eel biology toward management-oriented and adaptive research addressing environmental change.

Implications for conservation and management. The collaborative structure and subject focus indicate that otolith science has matured from method validation to decision-support for conservation. Stable-isotope and trace-element tools, such as LA-ICP-MS, now underpin discrimination between stocked and naturally recruited cohorts, evaluation of estuarine vs freshwater growth contributions, and identification of migratory contingents that disproportionately fuel reproduction. These applications are visible in the shift toward conservation-adjacent keywords and in results sections linking restocking efficacy to habitat connectivity and salinity history.

Network centrality of “migration,” “catadromous,” and “recruitment” aligns with current policy concerns about barriers, escapement, and life-stage bottlenecks, emphasizing that microchemical chronologies are most useful when paired with hydrological and passage data.

Open-access patterns also carry management consequences. With only ~33.6% of eel–otolith papers openly accessible, critical evidence for agencies and local stakeholders can remain functionally unavailable due to journal subscription requirements; yet some of the most influential articles in this domain are open, reinforcing that widening access could accelerate use of scientific findings in forming policy.

Limitations of the present analysis. As with any bibliometric synthesis, inferences are shaped by database and query design. Our bibliographic analysis results are only from Scopus, restricted to 1930–2023 journal articles returned by TITLE-ABS queries and refined through synonym merging and co-occurrence thresholds in VOSviewer. These decisions, while deliberate for consistency, can undercount regional outlets, non-English literature, and grey reports, and they weight fields unevenly by indexing practices (Sup. Figs. 1–2, Fig. 1; Methods). The country and institutional signals should therefore be considered as the indexed activity rather than a census of all work. Nevertheless, the internal coherence of the collaboration and keyword networks, together with convergence across multiple figures and tables, suggests that the major structural conclusions are robust.

Priorities going forward. Three gaps are persistent. First, species and stage balance: tropical anguillids and their yellow-eel phases remain under-sampled for age, growth, and movement analyses relative to *A. anguilla* and *A. japonica*; targeted Sr:Ca and isotope studies on these taxa would correct geographic and ontogenetic bias. Second, exposure biology: pollutant-specific contrasts in organotin and organochlorine burdens mapped onto otolith chronologies need replication across basins and species, with explicit links to growth reductions and migratory success. Third, use in management: otolith evidence should be integrated into passage design, stocking efforts, and basin-scale connectivity planning, with transparent tests of whether restocking returns reproductive value or simply relocates mortality risk. Collectively, these directions align with the field's current trajectory from descriptive chronologies to mechanistic, management-relevant reconstructions of eel life histories. By leveraging the global network illustrated here and by increasing access to high-value datasets, otolith science can continue to sharpen conservation strategies for anguillid eels under accelerating environmental change.

Author Contributions

Writing original draft: MK; Formal Analysis: MK; Investigation: MK; Conceptualization: MK; Revising & editing: All authors equally contributed; Supervision: TT; Funding acquisition: TT; Data curation: FAS; Methodology: GSH.

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Supplemental data

<https://doi.org/10.47605/tapro.v14i2.380>

Literature cited

- Arai, K., H. Itakura, A. Yoneta *et al.* (2019). Anthropogenic impacts on the distribution of wild and cultured Japanese eels in the Tone River watershed, Japan, from otolith oxygen and carbon stable isotopic composition. *Environmental Biology of Fishes*, 102(11): 1405–1420.
- Arai, K., H. Itakura, A. Yoneta *et al.* (2017). Discovering the dominance of the non-native European eel in the upper reaches of the Tone River system, Japan. *Fisheries Science*, 83(5): 735–742.
- Arai, T. (2014). Do we protect freshwater eels or do we drive them to extinction? *SpringerPlus*, 3: 534.
- Arai, T. (2020). Ecology and evolution of migration in the freshwater eels of the genus *Anguilla* Schrank, 1798. *Heliyon*, 6(10): e05255.
- Arai, T. (2022). Early life history and recruitment processes of a tropical anguillid eel *Anguilla marmorata* to the Pacific coast, as revealed by otolith Sr:Ca ratios and microstructure. *Biology*, 11(6): 822.
- Arai, T. & N. Chino (2017). Influence of water salinity on the strontium:calcium ratios in otoliths of the giant mottled eel *Anguilla marmorata*. *Environmental Biology of Fishes*, 100(3): 281–286.
- Arai, T. & N. Chino (2018). Opportunistic migration and habitat use of the giant mottled eel *Anguilla marmorata* (Teleostei: Elopomorpha). *Scientific Reports*, 8(1): 5666.
- Arai, T. & N. Chino (2022). Contribution of migratory types to the reproduction of migrating

- silver eels in a tropical eel, *Anguilla bicolor bicolor*. *Heliyon*, 8(5): e09333.
- Arai, T., I.J. Chai, Y. Iizuka & C.W. Chang (2020). Habitat segregation and migration in tropical anguillid eels, *Anguilla bengalensis bengalensis* and *A. bicolor bicolor*. *Scientific Reports*, 10(1): 12774.
- Arai, T. & S. Kimura (2022). Spatiotemporal variability of trace-element fingerprints in otoliths of Japanese eel (*Anguilla japonica*) and its use in tracing geographic origin. *Biology*, 11(12): 1733.
- Arai, T. & A. Takeda (2012). Differences in organochlorine accumulation accompanying life history in the catadromous eel *Anguilla japonica* and the marine eel *Conger myriaster*. *Ecotoxicology*, 21(4): 1260–1271.
- Bae, J.H., H.J. Bae, H.M. Park *et al.* (2018). Age determination and growth estimates of the white-spotted conger eel *Conger myriaster* (Brevoort, 1856) in marine waters of South Korea. *Journal of Applied Ichthyology*, 34(3): 542–549.
- Barić, O., T. Radocaj, A. Conides, N. Kitanovic, J. Jugdujakovic & A. Gavrilovic (2023). Functional morphology as an indicator of European eel population status. *Diversity*, 15(12): 1223.
- Beentjes, M.P. & D.J. Jellyman (2015). Growth patterns and age validation from otolith ring deposition in New Zealand longfin eels *Anguilla dieffenbachii* recaptured after 10 years at large. *Journal of Fish Biology*, 86(3): 924–939.
- Bonhommeau, S., E. Chassot, B. Planque *et al.* (2008). Impact of climate on eel populations of the Northern Hemisphere. *Marine Ecology Progress Series*, 373: 71–80.
- Borges, F.O., C. Santos, E. Sampaio *et al.* (2019). Ocean warming and acidification may challenge the riverward migration of glass eels. *Biology Letters*, 15(1): 20180627.
- Budimawan (1997). The early life history of the tropical eel *Anguilla marmorata* (Quoy & Gaimard, 1824) from four Pacific estuaries, as revealed from otolith microstructural analysis. *Journal of Applied Ichthyology*, 13(2): 57–62.
- Calizo, J.R., P. Ferrer, M.J. Velasquez *et al.* (2023). Bibliometric review of otolith research in Southeast Asia: species coverage and emerging directions. *Philippine Journal of Science*, 152(4): 1159–1176.
- Calles, O., I. Olsson, C. Comoglio *et al.* (2010). Size-dependent mortality of migratory silver eels at a hydropower plant, and implications for escapement to the sea. *Freshwater Biology*, 55(10): 2167–2180.
- Campana, S.E. (1999). Chemistry and composition of fish otoliths: pathways, mechanisms and applications. *Marine Ecology Progress Series*, 188: 263–297.
- Capoccioni, F., D.Y. Lin, Y. Iizuka, W.N. Tzeng & E. Ciccotti (2014). Phenotypic plasticity in habitat use and growth of the European eel (*Anguilla anguilla*) in transitional waters in the Mediterranean area. *Ecology of Freshwater Fish*, 23(1): 65–76.
- Castonguay, M. & C.M.F. Durif (2016). Understanding the decline in anguillid eels. *ICES Journal of Marine Science*, 73(1): 1–4.
- Chen, W., Y. Geng, S. Zhong, M. Zhuang & H. Pan (2020). A bibliometric analysis of ecosystem-services evaluation from 1997 to 2016. *Environmental Science & Pollution Research*, 27(19): 23503–23513.
- Chino, N. & T. Arai (2009). Relative contribution of migratory type on the reproduction of migrating silver eels (*Anguilla japonica*) collected off Shikoku Island, Japan. *Marine Biology*, 156(4): 661–668.
- Chino, N., C. Imai, H. Sakai & T. Arai (2017). Differences in the maturation level among life histories of the Japanese eel *Anguilla japonica* in the Nagata River, Japan. *Oceanological & Hydrobiological Studies*, 46(4): 472–477.
- Cuschieri, S. (2018). WASP: is open-access publishing the way forward? A review of the different ways in which research papers can be published. *Early Human Development*, 121: 54–57.
- Dai, Y., Y. Song, H. Gao, S. Wang & Y. Yuan (2015). Bibliometric analysis of research progress in membrane-water-treatment technology from 1985 to 2013. *Scientometrics*, 105(1): 577–591.
- Daverat, F., K.E. Limburg, I. Thibault *et al.* (2006). Phenotypic plasticity of habitat use by three temperate eel species, *Anguilla anguilla*, *A. japonica* and *A. rostrata*. *Marine Ecology Progress Series*, 308: 231–241.
- Debowski, P., R. Bernaś, M. Skóra & J. Morzuch (2020). Route selection, migration speed and mortality of silver eel passing through two small hydroelectric facilities. *Fisheries & Aquatic Life*, 28(3): 133–140.
- Denis, J., K. Mahé & R. Amara (2022). Abundance and growth of the European eels (*Anguilla anguilla* Linnaeus, 1758) in small estuarine habitats from the eastern English Channel. *Fishes*, 7(5): 249.
- Denis, J., K. Mahé, H. Tabouret *et al.* (2023). Relationship between habitat use and individual condition of European eel (*Anguilla anguilla*) in six estuaries of the eastern English Channel (Northeastern Atlantic Ocean). *Estuarine*,

- Coastal & Shelf Science*, 291: 108446.
- Dorow, M. & R. Arlinghaus (2012). The relationship between personal commitment to angling and the opinions and attitudes of German anglers towards the conservation and management of the European eel *Anguilla anguilla*. *North American Journal of Fisheries Management*, 32(3): 466–479.
- Durif, C., O.H. Diserud, O.T. Sandlund *et al.* (2020). Age of European silver eels during a period of declining abundance in Norway. *Ecology & Evolution*, 10(11): 4801–4815.
- Durif, C.M.F., M. Arts, F. Bertolini *et al.* (2023). The evolving story of catadromy in the European eel (*Anguilla anguilla*). *ICES Journal of Marine Science*, 80(9): 2253–2265.
- Fekri, L., R. Affandi, M.F. Rahardjo, T. Budiardi & C.P.H. Simanjuntak (2019). Growth of stunted elver of the Indonesian shortfin eel *Anguilla bicolor* McClelland, 1844 rearing in semi-natural media. *Jurnal Iktiologi Indonesia*, 19(2): 243–252.
- Graynoth, E. (1999). Improved otolith preparation, ageing and back-calculation techniques for New Zealand freshwater eels. *Fisheries Research*, 42(1–2): 137–146.
- Han, Y.S., K.M. Hsiung, H. Zhang *et al.* (2019). Dispersal characteristics and pathways of Japanese glass eel in the East Asian continental shelf. *Sustainability*, 11(9): 2466.
- Ilmasari, D., E. Sahabudin, F.A. Riyadi, N. Abdullah & A. Yuzir (2022). Future trends and patterns in leachate biological treatment research from a bibliometric perspective. *Journal of Environmental Management*, 318: 115594.
- Ishikawa, S., K. Suzuki, T. Inagaki *et al.* (2001). Spawning time and place of the Japanese eel *Anguilla japonica* in the North Equatorial Current of the western North Pacific Ocean. *Fisheries Science*, 67(6): 1097–1103.
- Jellyman, D. & K. Tsukamoto (2005). Swimming depths of offshore migrating longfin eels *Anguilla dieffenbachii*. *Marine Ecology Progress Series*, 286: 261–267.
- Jessop, B.M. (2021). Oceanic water temperatures less than 20 °C may partly account for bias in American eel elver otolith age estimates. *Marine & Coastal Fisheries*, 13(5): 614–624.
- Jessop, B.M., D.K. Cairns, I. Thibault & W.N. Tzeng (2007). Life history of American eel *Anguilla rostrata*: new insights from otolith microchemistry. *Aquatic Biology*, 1(3): 205–216.
- Kaifu, K. & K. Yokouchi (2019). Increasing or decreasing? Current status of the Japanese eel stock. *Fisheries Research*, 220: 105348.
- Kaifu, K., H. Maeda, K. Yokouchi *et al.* (2014). Do Japanese eels recruit into the Japan Sea coast? A case study in the Hayase River system, Fukui, Japan. *Environmental Biology of Fishes*, 97(8): 921–928.
- Kaifu, K., K. Yokouchi, T. Higuchi, H. Itakura & K. Shirai (2018). Depletion of naturally recruited wild Japanese eels in Okayama, Japan, revealed by otolith stable isotope ratios and abundance indices. *Fisheries Science*, 84(5): 757–763.
- Kanjuh, T., D. Mrdak, M. Piria *et al.* (2018). Relationships of otolith dimensions with body length of European eel *Anguilla anguilla* (Linnaeus, 1758) from the Adriatic catchment of Montenegro. *Acta Adriatica*, 59(1): 91–96.
- Kasai, A., A. Yamazaki, H. Ahn *et al.* (2021). Distribution of Japanese eel *Anguilla japonica* revealed by environmental DNA. *Frontiers in Ecology & Evolution*, 9: 638574.
- Kern, Z., M. Kázmér, T. Müller *et al.* (2017). Fusiform vateritic inclusions observed in European eel (*Anguilla anguilla* L.) sagittae. *Acta Biologica Hungarica*, 68(3): 267–278.
- Kita, T. & K. Tachihara (2020). Age, growth and gonadal condition of the giant mottled eel *Anguilla marmorata* in Okinawa-jima Island, Japan. *Environmental Biology of Fishes*, 103(8): 927–938.
- Koster, W.M., K. Aarestrup, K. Birnie-Gauvin *et al.* (2021). First tracking of the oceanic spawning migrations of Australasian short-finned eels (*Anguilla australis*). *Scientific Reports*, 11: 16313.
- Kotake, A., T. Arai, M. Ohji *et al.* (2004). Application of otolith microchemistry to estimate the migratory history of Japanese eel *Anguilla japonica* on the Sanriku Coast of Japan. *Journal of Applied Ichthyology*, 20(2): 150–153.
- Kuroki M., M.J. Miller, K. Tsukamoto (2014). Diversity of early life history traits in freshwater eels and the evolution of their oceanic migrations. *Canadian Journal of Zoology*, 92(9): 749–770.
- Kuroki, M., N. Mikawa, F. Mizuta *et al.* (2020). Sea-resident Japanese eel collected from Kozushima Island, Japan. *Ichthyological Research*, 67(3): 451–455.
- Lamson, H.M., J.C. Shiao, Y. Iizuka, W.N. Tzeng & D.K. Cairns (2006). Movement patterns of American eels (*Anguilla rostrata*) between salt and freshwater in a coastal watershed, based on otolith microchemistry. *Marine Biology*, 149(6): 1567–1576.
- Lecomte-Finiger, R. (1992). Growth history and age at recruitment of European glass eels

- (*Anguilla anguilla*) as revealed by otolith microstructure. *Marine Biology*, 114: 205–210.
- Lin, Y.J., B.M. Jessop, O.L.F. Weyl, Y. Iizuka, S.H. Lin & W.N. Tzeng (2015). Migratory history of African longfinned eel *Anguilla mossambica* from Maningory River, Madagascar: discovery of a unique pattern in otolith Sr:Ca ratios. *Environmental Biology of Fishes*, 98(1): 457–468.
- Martin, M.H. (1995). The effects of temperature, river flow and tidal cycles on the onset of glass eel and elver migration into fresh water in the American eel. *Journal of Fish Biology*, 46(5): 891–902.
- Marui, M., T. Arai, M.J. Miller, D.J. Jellyman & K. Tsukamoto (2001). Comparison of early life history between New Zealand temperate eels and Pacific tropical eels revealed by otolith microstructure and microchemistry. *Marine Ecology Progress Series*, 213: 273–284.
- Matić-Skoko, S., J. Ferri, P. Tutman *et al.* (2012). The age, growth and feeding habits of the European conger eel *Conger conger* (L.) in the Adriatic Sea. *Marine Biology Research*, 8(10): 1012–1018.
- McCleave, J.D. (2008). Contrasts between spawning times of *Anguilla* species estimated from larval sampling at sea and from otolith analysis of recruiting glass eels. *Marine Biology*, 155(3): 249–262.
- Meulenbroek, P., U. Hammerschmied, S. Schmutz *et al.* (2020). Conservation requirements of European eel (*Anguilla anguilla*) in a Balkan catchment. *Sustainability*, 12(20): 8535.
- Milošević, D., M. Bigović, D. Mrdak, I. Milašević & M. Piria (2021). Otolith morphology and microchemistry fingerprints of European eel *Anguilla anguilla* (Linnaeus, 1758) stocks from the Adriatic Basin in Croatia and Montenegro. *Science of the Total Environment*, 786: 147364.
- Moura, A., E. Dias, R. López & C. Antunes (2022). Regional population structure of the European eel at the southern limit of its distribution revealed by otolith shape signature. *Fishes*, 7(3): 139.
- Mu, X., C. Zhang, B. Xu, Y. Ji, Y. Xue & Y. Ren (2022). Varying growth rates of a marine eel, the whitespotted conger (*Conger myriaster*), are explained by the interaction between seasonal temperature and prey availability. *Marine Biology*, 169(1): 7.
- Mu, X., C. Zhang, C. Zhang *et al.* (2018). Age determination for whitespotted conger *Conger myriaster* through somatic and otolith morphometrics. *PLoS ONE*, 13(9): e0204317.
- Mu, X., C. Zhang, C. Zhang, J. Yang & Y. Ren (2021). Age-structured otolith chemistry profiles revealing the migration of *Conger myriaster* in China Seas. *Fisheries Research*, 239: 105938.
- Ohji, M., H. Harino & T. Arai (2009). Variation in organotin accumulation in relation to the life history in the Japanese eel *Anguilla japonica*. *Estuarine, Coastal & Shelf Science*, 84(1): 28–36.
- Osmaleli, D.W., Widiyaningtyas & T. Kusumastanto (2023). Economic impact of *Anguilla bicolor* aquaculture on local communities in Banyuwangi Regency. *Journal of Natural Resources & Environmental Management*, 13(1): 114–121.
- Otake, T., Y. Amano, K. Shirai *et al.* (2019). Evaluation from otolith Sr stable isotope ratios of possible juvenile growth areas of Japanese eels collected from the West Mariana Ridge spawning area. *Fisheries Science*, 85(3): 483–493.
- Panfili, J., C. Boulenger, C. Musseau & A.J. Crivelli (2022). Extreme variability in European eel growth revealed by an extended mark-recapture experiment in southern France and implications for management. *Canadian Journal of Fisheries & Aquatic Sciences*, 79(4): 631–641.
- Pike, C., J. Casselman, V. Crook *et al.* (2023). *Anguilla rostrata*. *The IUCN Red List of Threatened Species* 2023: e.T191108A129638652. Accessed on 12 November 2024.
- Pike, C., V. Crook & M. Gollock (2020). *Anguilla anguilla*. *The IUCN Red List of Threatened Species* 2020: e.T60344A152845178. Accessed on 13 November 2024.
- Pike, C., K. Kaifu, V. Crook, D. Jacoby & M. Gollock (2020). *Anguilla japonica* (amended version of 2020 assessment). *The IUCN Red List of Threatened Species* 2020: e.T166184A176493270. Accessed on 13 November 2024.
- Podda, C., J. Culurgioni, R. Diciotti *et al.* (2023). Exploring European eel *Anguilla anguilla* (L.) habitat differences using otolith analysis in central western Mediterranean rivers and coastal lagoons from Sardinia. *Fishes*, 8(8): 390.
- Rohtla, M., F. Daverat, M.T. Arts *et al.* (2023). Habitat use and growth of yellow-stage European eel in coastal and freshwater ecosystems in Norway. *Canadian Journal of Fisheries & Aquatic Sciences*, 80(1): 14–26.
- Rohtla, M., M. Silm, J. Tulonen *et al.* (2021). Conservation restocking of the imperilled European eel does not necessarily equal conservation. *ICES Journal of Marine Science*, 78(1): 101–111.

- Sahabudin, E., J. Prayitno, H. Susanti *et al.* (2024). Future trends and patterns in diatom fatty acid research from a bibliometric standpoint. *Biocatalysis & Agricultural Biotechnology*, 61: 103373.
- Sallami, B. & M. Ben Salem (2017). Age and growth of *Conger conger* (Congridae) from the north coast of Tunisia. *Cybium*, 41(3): 237–243.
- Shirai, K., T. Otake, Y. Amano *et al.* (2018). Temperature and depth distribution of Japanese eel eggs estimated using otolith oxygen stable isotopes. *Geochimica et Cosmochimica Acta*, 236: 373–383.
- Silm, M., P. Bernotas, M. Haldna, A. Järvalt & T. Nõges (2017). Age and growth of European eel *Anguilla anguilla* (Linnaeus, 1758) in Estonian lakes. *Journal of Applied Ichthyology*, 33(2): 236–241.
- Simon, J. (2015). Age and growth of European eels (*Anguilla anguilla*) in the Elbe River system in Germany. *Fisheries Research*, 164: 278–285.
- Smith, D.R., P.L. Fackler, S. Eyler, L.V. Ortiz & S.A. Welsh (2017). Optimization of decision rules for hydroelectric operation to reduce both eel mortality and unnecessary turbine shutdown: a search for a win-win solution. *River Research & Applications*, 33(8): 1279–1285.
- Starrs, D., B.C. Ebner & C.J. Fulton (2014). All in the ears: unlocking the early life history biology and spatial ecology of fishes. *Biological Reviews*, 91(1): 1–21.
- Tahri, M. & J. Panfili (2023). Thirteen-year population survey of the critically endangered European eel in the southern Mediterranean region (Algeria). *Journal of Fish Biology*, 102(6): 1492–1502.
- Tamario, C., O. Calles, J. Watz, P.A. Nilsson & E. Degerman (2019). Coastal river connectivity and the distribution of ascending juvenile European eel (*Anguilla anguilla* L.): implications for conservation strategies regarding fish passage solutions. *Aquatic Conservation: Marine & Freshwater Ecosystems*, 29(4): 612–622.
- Tan, H., J. Li, M. He *et al.* (2021). Global evolution of research on green energy and environmental technologies: a bibliometric study. *Journal of Environmental Management*, 297: 113131.
- Teichert, N., B. Bourillon, K. Suzuki *et al.* (2023). Biogeographical snapshot of life-history traits of European silver eels: insights from otolith microchemistry. *Springer Nature*, 85(39): 1–12.
- Teixeira da Silva, J.A. (2020). CiteScore: advances, evolution, applications and limitations. *Publishing Research Quarterly*, 36(3): 459–468.
- Todd, P.R. (1980). Size and age of migrating New Zealand freshwater eels (*Anguilla* spp.). *New Zealand Journal of Marine & Freshwater Research*, 14(3): 283–293.
- Trancart, T., A. Carpentier, A. Acou *et al.* (2020). When “safe” dams kill: analyzing combination of impacts of overflow dams on the migration of silver eels. *Ecological Engineering*, 145: 105741.
- Tsukamoto, K. (1990). Recruitment mechanism of the eel *Anguilla japonica* to the Japanese coast. *Journal of Fish Biology*, 36(5): 659–671.
- Tsukamoto, K. & T. Arai (2001). Facultative catadromy of the eel *Anguilla japonica* between freshwater and seawater habitats. *Marine Ecology Progress Series*, 220: 265–276.
- Tsukamoto, K., T. Otake, N. Mochioka *et al.* (2003). Seamounts, new moon and eel spawning: the search for the spawning site of the Japanese eel. *Environmental Biology of Fishes*, 66(3): 221–229.
- Tzeng, W.N. (1996). Effects of salinity and ontogenetic movements on strontium:calcium ratios in the otoliths of the Japanese eel *Anguilla japonica* Temminck & Schlegel. *Journal of Experimental Marine Biology & Ecology*, 199(1): 111–122.
- Vaughan, L., D. Brophy, C. O’Toole *et al.* (2021). Erratum: growth rates in a European eel *Anguilla anguilla* (L., 1758) population show a complex relationship with temperature over a seven-decade otolith biochronology. *ICES Journal of Marine Science*, 78(8): 3012.
- Wickström, H. & N.B. Sjöberg (2014). Traceability of stocked eels: the Swedish approach. *Ecology of Freshwater Fish*, 23(1): 33–39.
- Williamson, M.J., C. Pike, M. Gollock, D.M.P. Jacoby & A.T. Piper (2023). Anguillid eels. *Current Biology*, 33(17): R888–R893.
- Williamson, M., D. Jacoby & A.T. Piper (2023). The drivers of anguillid eel movement in lentic water bodies: a systematic map. *Reviews in Fish Biology & Fisheries*, 33: 147–174.
- Yokouchi, K., J. Aoyama, H.P. Oka & K. Tsukamoto (2008). Variation in the demographic characteristics of yellow-phase Japanese eels in different habitats of the Hamana Lake system, Japan. *Ecology of Freshwater Fish*, 17(4): 639–652.
- Yokouchi, K., N. Fukuda, M.J. Miller *et al.* (2012). Influences of early habitat use on the migratory plasticity and demography of Japanese eels in central Japan. *Estuarine, Coastal & Shelf Science*, 107: 132–140.
- Zan, N.D., A. Sarbini, H. Taha *et al.* (2020). Occurrence and ecological implication of a tropical anguillid eel *Anguilla marmorata* in Brunei Darussalam, Borneo Island. *Zoologia*, 37: e20190243.