Spatio-Seasonal Habitat Suitability Model of *Anisakis* spp. in Chub Mackerel (*Scomber Japonicus*) as a Scientific-Based Approach to Provide Safety Assessment Policy of Fisheries Product in Indonesia

Izhamil Hidayah[1*], Sutomo[1], Eko Pujiono[1], Muhammad Hadi Saputra[1], Nida Humaida[1], Hedi Indra Januar[1], Yusnita Mirna Anggraeni[2], Herti Windya Puspasari[2], Radestya Triwibowo[3], Novalia Rachmawati[3], Sri Iswani[4], Yusma Yennie[5], and Agung Santoso[6]

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[1] Research Center for Ecology and Ethnobiology, National Research and Innovation Agency Republic of Indonesia (BRIN), Cibinong, Indonesia

[2] Research Center for Public Health and Nutrition, National Research and Innovation Agency Republic of Indonesia (BRIN), Cibinong, Indonesia

[3] Research Center for Food Technology and Processing, National Research and Innovation Agency Republic of Indonesia (BRIN), Gunungkidul, Indonesia

[4] Research Center for Fisheries, National Research and Innovation Agency Republic of Indonesia (BRIN), Cibinong, Indonesia

[5] Research Center for Marine and Fisheries Product Processing and Biotechnology, Jakarta, Indonesia

[6] Fish Quarantine Inspection Agency, Ministry of Fisheries and Marine Affairs, Jakarta, Indonesia

*Corresponding Author: izha002@brin.go.id

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Abstract

The infestation of *Anisakis* spp. in Chub mackerel (*Scomber japonicus*) may have significant health and socioeconomic implications. Understanding the spatio-seasonal occurrence of *Anisakis* spp. in its host, *S. japonicus*, is crucial ecologically and for effective management. This research aimed to develop a predictive map (spatial-seasonal patterns) for *Anisakis*'s infestation in *S. japonicus* using the maximum entropy (MaxEnt) algorithm. *Anisakis* spp. and S. *japonicus* occurrences were obtained through a comprehensive Bibliographic analysis of the Scopus database (2017-2022) and the Ocean Biodiversity Information System (OBIS) database to collect the necessary data. Environmental predictors were sourced from the Global Marine Environment Data. The resulting model demonstrated a reliable performance, as indicated by an Area Under Curve (AUC) value on the Receiver Operating Characteristic (ROC) chart exceeding 0.8. The findings of this study revealed that the infestation of *Anisakis* spp. in *S. japonicus* is projected to be more prevalent during the fourth quarter of each year. Furthermore, the environmental factors influencing the infestation were identified as diffuse attenuation, water depth, and distance from the coast. These research outcomes can be a foundational reference for developing an effective control system for inspecting fresh or frozen fish within the quarantine department. By utilizing the spatial-seasonal patterns and environmental predictors identified in this study, authorities can implement targeted measures to prevent and mitigate the infestation of *Anisakis* spp. in *S. japonicus*, safeguarding public health and maintaining the quality of fish products.

Keywords: Anisakis spp., Habitat Suitability Model, Scomber japonicus, Spasio-seasonal analysis, public health Maximum entropy algorithm (MaxEnt)

Introduction

Nematode infestation (*Anisakis* spp.) in fish such as Chub mackerel (*Scomber japonicus*) is a problem in seafood safety of marine-derived products. Human health can be affected if infected by *Anisakis spp.* due to accidentally eating raw or improperly cooked infested *S. japonicus* such as sushi or fish fillet (Klimpel et al., 2010; Llarena-Reino et al., 2015). Although *Anisakis* spp. can be deactivated (killed) through the heating process during cooking, there are indications that the allergens produced by these parasites are heat-stable, so they are not degraded or damaged by heating. Furthermore, in a food processing environment, Anisakidae larvae display sensitivity to salt under specific conditions but may survive in short-term periods in food matrices. For instance, larvae found in brined herring, which consists of 6.3% of salt and 3.7% of acetic acid, were observed to survive for up to 28 days. The larvae survived only for five days in brined anchovies containing 12% salt and 10% acetic acid (EFSA Panel on Biological Hazards (BIOHAZ) 2011).

Anisakis spp. induces anisakiasis in humans, marked by symptoms including digestive tract sores, nausea, vomiting, fever, and bloody diarrhea within 5-7 days, and can also elicit allergic manifestations like skin rashes and itching (Sangaran & Sundar, 2016; Ishikura & Namiki, 1989). Anisakis species infestations have the potential of causing adverse economic and social impacts on the seafood industry, which includes the canning sector. It is anticipated to result in a decline in the product's selling power and commercial worth, costing the fish industry up to millions of dollars annually in financial losses (Llarena-Reino et al., 2015). For example, the issue of worm contamination in canned *S. japonicus* fish in the Indonesia market in 2018 led to food recall of canned fish from local producers, causing the employee termination of thousands of workers from at least 26 fish canning companies (Noersativa & Zuraya, 2018; Sutari, 2016). The infested raw material of frozen *S. japonicus* was identified as an imported fish caught from the Atlantic and Pacific Oceans (Triwibowo et al., 2023).

Anisakis' infestation in some marine-pelagic fish species is known as a natural incidence, especially in wild-caught fish, including sardines and mackerel (Mladineo & Poljak, 2013), hence utilizing parasite-free fish as a raw material in canned fish industries is difficult to be applied. One potential approach to eliminating or reducing the occurrence of Anisakis is controlling the source of raw material (Triwibowo et al., 2023) by understanding the ecological distribution of the parasite in fish from different oceans or seas. The optimum temperature for developing Anisakis eggs was between 3-25°C. Higher temperatures reduced the hatching rates up to 0%. Specifically for *A. simplex s.s.*, the larvae are more adapted to lower temperatures, while *A. pegreffii* larvae showed higher adaptability to warmer environments. This distinctive adaptability determined the distribution patterns for both species (Gomes et al., 2023). The survival time of *Anisakis simplex* larvae was increased with salinity. Furthermore, light exposure at 13°C significantly reduced the hatching time for *A. simplex* eggs. Both conditions support the hypothesis that *A. simplex* is acclimated to offshore pelagic marine habitats (Højgaard 1998).

The prevalence of *Anisakis*' infestation in Scomber fish (including *S. scombrus*, *S. japonicus*, and *Scomber* spp.) have been reported and documented from several studies in different source or area such as Karaburun Peninsula – Mediterranean Sea (Ozuni et al., 2021); Northeast Atlantic (Pekmezci, 2014; Levsen et al., 2018); Japan Sea (Suzuki et al., 2021): Korean Peninsula (Bak et al., 2014); Egypt (Abdelsalam et al., 2020). Based on the outcomes of these studies, the prevalence rates of *Anisakis*' infestations in *S. japonicus* exceed 50%, indicating an inevitability in their occurrence in the fish. The variability in the sampling periods across these studies may not represent the actual prevalence data that can be used to predict the occurrence of *Anisakis* spp. in the fish. These data gaps can be addressed by predicting *Anisakis* spp and its host using the habitat suitability model.

Ecologically, the spatial and temporal abundance of zoonotic parasites *Anisakis spp.* in fish *S. japonicus* host can be predicted based on environmental parameters and the spatial occurrence of the host by using the species distribution model or habitat suitability model technique, e.g., by MaxEnt/Maximum Entropy algorithm (*Kuhn* et al., 2016). The model may serve as a reliable, credible, and repeatable tool for mapping the suitable habitat for an observed species (Sofaer et al., 2019). Previous studies by MaxEnt and Land Distance (LD) algorithm were conducted to predict the distribution of *Pseudoterranova decipiens* and *Anisakis spp.* in 37 possible hosts, including copepods, squid, and marine mammals (Alt et al., 2019; Kuhn et al., 2016). However, there is limited information regarding the probability model of *Anisakis'* infestation in *S. japonicus*, which was caught in the Atlantic or Pacific oceans.

In this research, *S. japonicus* was chosen as the primary host for Anisakis due to its frequent role as a pelagic fish species hosting *Anisakis*' larvae. This selection is supported by empirical evidence indicating the high prevalence and abundance of *Anisakis* spp. in *S. japonicus*, making it an ideal subject for investigating the infection dynamics associated with this parasite (Mladineo & Poljak, 2014; Ozuni et al., 2019). Additionally, the substantial dispersal capacity of pelagic fish, including *S. japonicus*, crucially contributes to gene flow within *Anisakis* spp. parasite populations (Cipriani et al., 2022). This further validates the rationale for designating it as the primary host in *Anisakis'* research. Moreover, *S. japonicus* is one of Indonesia's predominant species widely used as raw material in fish canning industries (Triwibowo et al., 2023). Hence, it is necessary to identify the potential S. *japonicus* as a primary host of *Anisakis*' infestation based on the perspective of the fish canning industries.

This research aimed to generate a predictive map of spatial-seasonal patterns for *Anisakis*' infestation in *S. japonicus*, using the maximum entropy algorithm (MaxEnt) approach. MaxEnt is a species distribution or habitat suitability model that uses machine learning as a basis for its analysis (Phillips et al., 2004). The data obtained will be analyzed and modeled repeatedly until an output with a high level of validity is obtained through model validation using the ROC curve (Phillips et al., 2006). The results of this study could also be used by the Indonesian fish quarantine authorities as a baseline to develop a control system for fresh or frozen fish inspection.

Material and Methods

Research Design

The research was conducted by a computational ecology design that combined quantitative methods with ecological correspondence between biotic populations and spatio-temporal environmental conditions. This research aimed to calculate the spatio-temporal match between the seasonal peak of *S. japonicus* catchment and *Anisakis's* occurrence related to the environmental condition.

S. japonicus and Anisakis' Occurrence Data Collection

The distribution of *S. japonicus* was obtained from the global Ocean Biodiversity Information System (OBIS) database from 2017-2022. Incomplete or repeated data were excluded. Meanwhile, the occurrence of *Anisakis spp*. was collected from a Bibliographic analysis of scientific publications listed in the Scopus database using the keywords "*Anisakis* spp." and "anisakiasis" within the last five years (2017-2022). One hundred thirteen articles met the criteria above; however, only 98 articles provided reliable coordinates of *Anisakis* spp.' occurrence, which were used in this study. Spatial rarefy data processing was carried out using SDMtoolbox 2.0 with a spatial distance of 10 km to reduce the effects of spatial autocorrelation (Beeman et al., 2021; Brown et al., 2017). The coordinates of each data were then tabulated and saved into CSV files for further analysis.

Environmental Data Collection

The environmental parameters used in this research were distance to land, surface temperature, depth, salinity, and primary productivity of seawater (Kuhn et al., 2016). The data were obtained from Global Marine Environment Data (GMED). GMED provides environmental layers from different sources of current, past, and future climatic, biological, and geophysical environmental conditions. The data were presented in standard formats and resolutions, with the spatial projection synchronized to the previous biotic data. The levels of environmental data were loaded at a spatial resolution of 5 arc minutes (= 0.083 decimal degrees) and rescaled at the computational spatial resolution of 1 degree.

Habitat Suitability Model Analysis

The occurrence an environmental data were processed and modeled by the MaxEnt algorithm with SDMToolbox 2.0 (Brown, 2014) to predict the suitable habitat for *Anisakis spp*. and *S. japonicus*. The model was trained with 60% occurrence data and 40% for model calibration (Simon-Nutbrown et al., 2020). Model validation used the receiver operating characteristic curve (ROC Curve) with a two-dimensional graph to describe a species's existence in the prediction model with the reality of existence in nature (Saputra & Lee, 2021).

Results and Discussion

The Global and Local Occurrence of *S. japonicus* and *Anisakis* spp.

Tracing the existence of the host species *S. japonicus* in the Global Biodiversity Information Facility (GBIF), the database produced 9518 data (Figure 1). The spatial occurrences of *S. japonicus* were detected in northern America (8372 data), western Africa (659 data), Southern America (137 data), Eastern Asia (218 data), Southern Europe (63 data), Southern Africa (48 data), Australia (6 data), West Asia (5 data), North Pacific (6 data), Southeast Asia (3 data) and Eastern Africa (1 data). According to the data retrieved from AquaMaps.org (https://www.aquamaps.org/receive.php?type_of_map=regular&map=cached), the geographical distribution of *S. japonicus* extends to Indonesian waters. Nevertheless, it is noteworthy that studies addressing the distribution of this species in the region are presently limited. More occurrences were detected in the second (April–June) (5965 occurrences) and fourth (October-December) quarters (1119 occurrences). In contrast, sub-tropical regions showed different patterns with nearly consistent data across temporal quarters despite local spatial shifts.

As displayed in Figure 1, Northern America, Western Africa, and Northern Asia were the primary regions dominating the world's capture fisheries production of *S. japonicus*. The occurrences of *S. japonicus* data are based on research within the species' catchment area. This result suggested that the seasonal migration of pelagic animals only occurs locally. On the other hand, the subtropical area showed continuous production of *S. japonicus* and was unaffected by seasonal variations. The presence of *S. japonicus* in tropical regions (West Africa) seems to experience seasonal dynamics compared to subtropical regions.

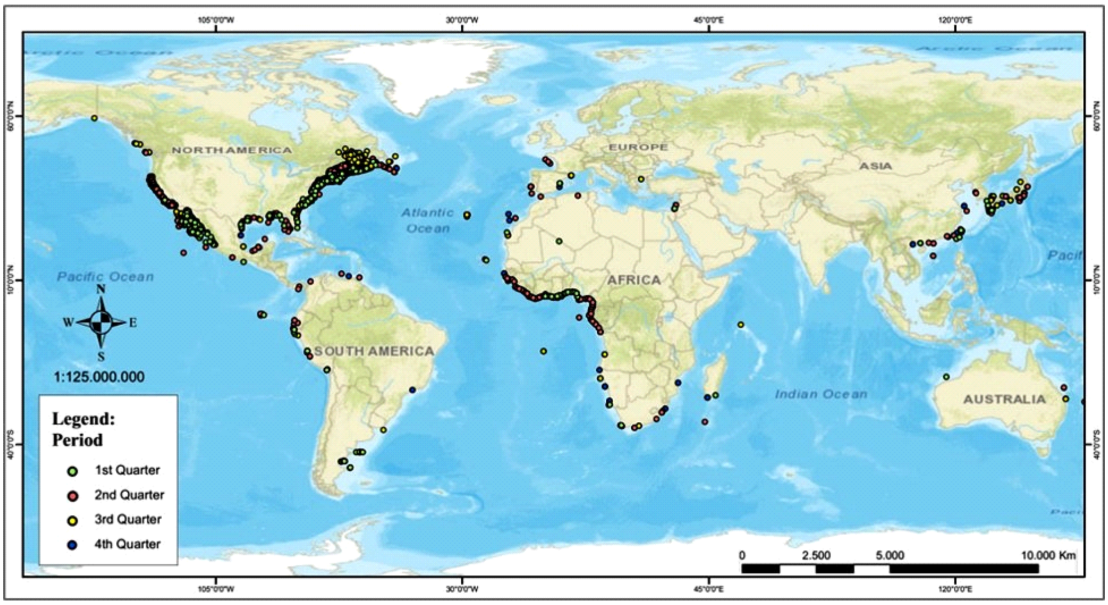

Figure 1. Spatio-seasonal occurrence of *Scomber japonicus.*

Bibliographic analysis of the Scopus database revealed a consistent number of yearly published articles (40-65 articles) related to *Anisakis* spp. during 2017-2022 (Figure 2). The top 15 studies of these articles collected the *Anisakis*' infestation in the European continent, followed by Southern America (Brazil and Argentina), Australia-Oceania (Australia), Northern America (US), and Asia (Indonesia). These studies reported that the presence of *Anisakis* spp. in mackerel products was predominantly detected in South America and Australia-Oceania, which are the major subtropical regions producing *S. japonicus*. Furthermore, The Bibliographic search resulted in 32 articles on *Anisakis*' occurrences from several locations in Indonesia (Figure 3), including Java Island, Bali, Aceh, and Kupang Islands. Based on data on the publication output per continent, Indonesia ranked second after Australia in producing publications related to the spatio/temporal distribution of the parasite *Anisakis* spp. in fish. This finding indicates the importance of research on the spatio-temporal occurrence of this fish parasite within Indonesian territory.

Environmental Data

The global environmental data of this study were obtained from GMED (Global Marine Environmental Datasets). Table 1 shows the environmental factors that influence *Anisakis* spp.' infestation in *S. japonicus*, such as diffuse attenuation, distance to land, and depth. The data highlighted several important contributing variables, such as Sea Surface Temperature (SST) during the period from October to March, the diffuse attenuation coefficient (January – March period), depth (April–June period), and distance to land (April–December). Despite being available in large numbers throughout the year, the distribution of *S. japonicus* is not a predictive factor for *Anisakis*' infection in this biota.

Figure 2. Bibliographic reports of *Anisakis*' occurrences in the Scopus database (2017-2022).

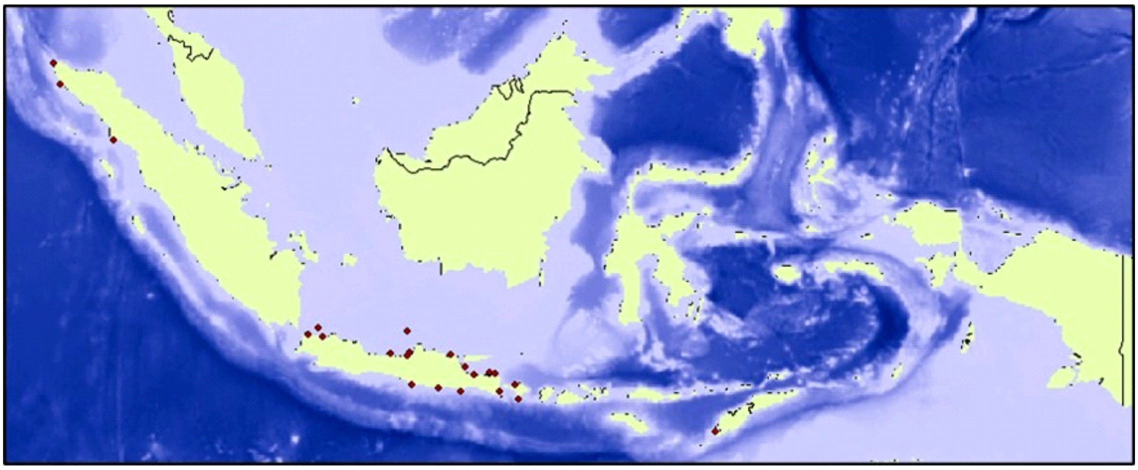

Figure 3. Occurrence of *Anisakis* spp. in Indonesia based on the Scopus database (1974-2022).

Table 1. The significant environmental predictor (jackknife) of *Anisakis* spp. infestation in *S. japonicus*

Variable Layers	January to March		April to June		July to September		October to December	
	% cont	Per. imp	% cont	Per. imp	% cont	Per. imp	% cont	Per. imp
Mean sea surface temperature (°C)	3.3	44.4	0	0.4	0.8	1.1	40.4	48.4
Diffuse attenuation coefficient	69.5	40.7	8.6	6.6	0	0	0	0
Depth (m)	7.6	4.7	45.4	39.8	12.8	6	0	0
Land distance (km x 100 (Euclid.Dist))	3.9	2.8	3.5	38.4	20	92.1	58.9	48.9
S. japonicus distribution quarter of the year	1.1	0.2	0	0	25.1	0.3	0.4	0.8
Slope (degree)	0.1	5.3	0	0	0	0	0	0
Wave height (m)	12.8	1.7	39	9.2	41	0.4	0	0

Note: % cont (Percent Contribution of each environment variable to the resulting model) and Per. Imp. (Permutation Importance explains the importance of each variable to the resulting model, either without or with only the variable itself). The results of this study were consistent with the findings of Bosch et al. (2018), which identified

SST as the dominant factor affecting nektonic and planktonic biota in the water column, including mackerel and *Anisakis* spp. In addition, the diffuse attenuation coefficient also showed similar observations as a seasonal predictor from January to March. However, our findings differed regarding the predictors between April and September, which included distance to terrestrial and depth factors.

The result shows that the significant predictors influencing *Anisakis*' infestation in *S. japonicus* varied across quarters. This highlighted the dynamics of a multi-predictor interaction that can affect marine biota at a particular time. Similar dynamics were observed in temporal modeling studies conducted by Edrén et al. (2010) and Teng et al. (2021), where different environmental factors were identified as important contributors to biota occurrence in different seasons. The habitat suitability model (Figure 5) indicates that the infestation of *Anisakis* spp. in *S. japonicus* shows spatiotemporal dynamics, with high temporal infestations predicted to occur, especially in the fourth quarter of each year. The area with subtropical season has a higher possibility of the occurrence of *S. japonicus*. Most of the area is in the coastal region, and different locations were found regarding the seasonal impact, such as in the coastal waters of Korea and the northwest Pacific Ocean (Kim et al., 2023). *Anisakis*' distribution infected the marine fish, especially in the waters of the Northern Hemisphere (Bilska-Zaj¹c et al.,2015). Fluctuations in environmental factors, such as temperature and salinity, are believed to affect Anisakis spp's growth indirectly. Hydrological factors, in particular, affect the distribution of phytolactones and the composition of zooplastones, which serve as the first link in the life cycle of *Anisakis* spp. (Mladineo & Poljak, 2013).

In contrast, the environmental data for *S. japonicus* indicated optimal conditions throughout the year. SST, diffuse attenuation coefficient, depth, and distance to terrestrial are environmental factors predicted to be associated with *Anisakis* spp. infestation in the host *S. japonicus*. These results are in line with research conducted by Pulleiro-Potel et al. (2015). Their finding revealed no significant correlation between the prevalence of *Anisakis* spp. and the geographic location of the fishery. Still, it highlighted the importance of water depth and proximity to land in determining the likelihood of host infestation by this parasite. In addition, wet environmental conditions and humid seasons with higher rainfall triggered higher infestations than dry seasons (Dione et al., 2014).

Habitat Suitability Model of Anisakis spp. Infestation in *S. japonicus*

MaxEnt analysis showed that the ROC chart's Area Under Curve (AUC) value was more than 0.8, indicating a highly reliable and precise model (Table 2). The model included annual and seasonal temporal prediction maps, as shown in Figures 4 and 5.

Regarding the annual distribution, *Anisakis* spp. and *S. japonicus* showed suitable habitats in several locations throughout the year, especially in subtropical areas (Figure 4). The northern subtropical regions, such as China, Japan, Europe, and the western and eastern coasts of America, and the southern regions, including South America, South Africa, Australia, and New Zealand, provided suitable habitats supporting Anisakis's growth. Although the optimal environments within the tropical regions were relatively scarce, they can be found in South America, Western Africa, Egypt, and Indonesia equatorial areas.

Regarding seasonal distribution, the environmental factors significantly shape the optimal habitat for *Anisakis*' growth (Figure 5). The highest seasonal distribution was detected during the first quarter of each year, followed by a decline in the second and third quarters and a subsequent increase in the fourth quarter. Even though the highest parasite occurrence was detected in the first quarter, it was not the peak season of *S. Japonicus* catchment. The peak of *S. japonicus* catchment is predicted to occur in the year's fourth quarter. Thus, the model algorithm predicts the occurrence of *Anisakis*' infestation in *S. japonicus* aligned closely with the habitat pattern of *Anisakis* spp. with a one-quarter forward shift from the fourth quarter to the end of the first quarter annually (Figure 6).

The Implication to Importation of *S. japonicus* in Indonesia

The average import of *S. japonicus* in Indonesia reached 48,372 tons/year, with an average valuation of 684 billion/year. Based on the fish importation database released by FQIA (2022), a significant import decline occurred from 2017-2018 to 2019-2022 (Table 3). As previously discussed, this decrease might be attributed to parasite infestation in canned fish in Indonesia's market in 2018, which significantly affected the importation of mackerel to Indonesia. The distrust rapidly occurred due to the presence of *Anisakis*' larvae in the canned fish, which correlated to the product's low quality, according to the consumer perspective. This problem significantly impacted the company's sales and resulted in a financial loss of up to billions of rupiah (millions of USD) (Sutari 2018). The additional result was firing of thousands of workers from 26 canning businesses in Indonesia (Noersativa

Table 2. The area under the curve value of the ROC graphic from the maxent model for each species

Seasonal Quarter	AUC Value		
	Anisakis spp.	*S. japonicus*	Infestation *Anisakis* spp. in *S. japonicus*
January – March	0.817	0.987	0.96
April – June	0.949	0.982	0.983
July – September	0.993	0.988	0.993
October – December	0.936	0.987	0.902

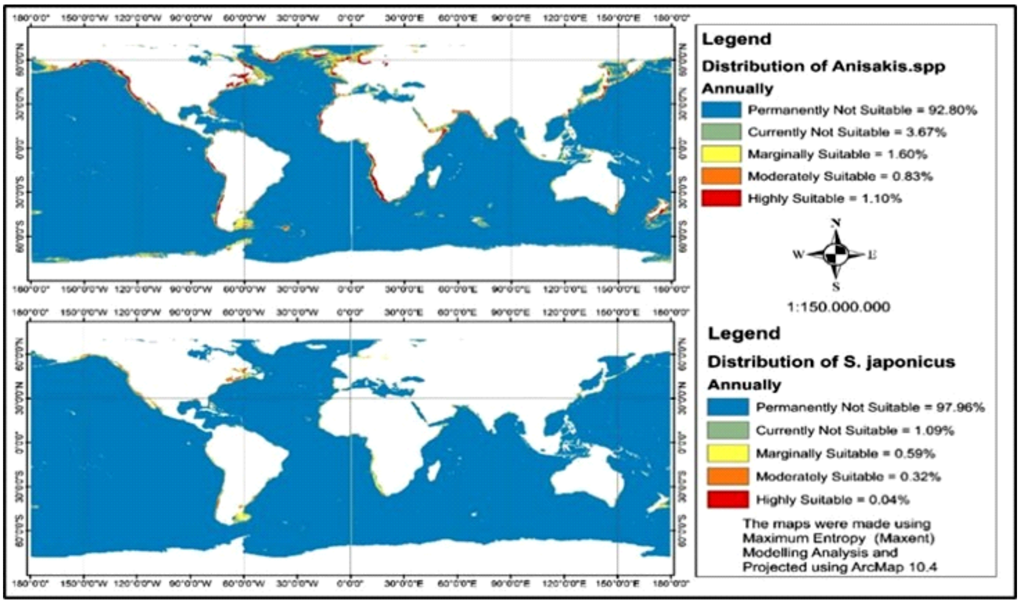

Figure 4. Annual habitat suitability model of *Anisakis* spp. and *S. japonicus* from environmental factor.

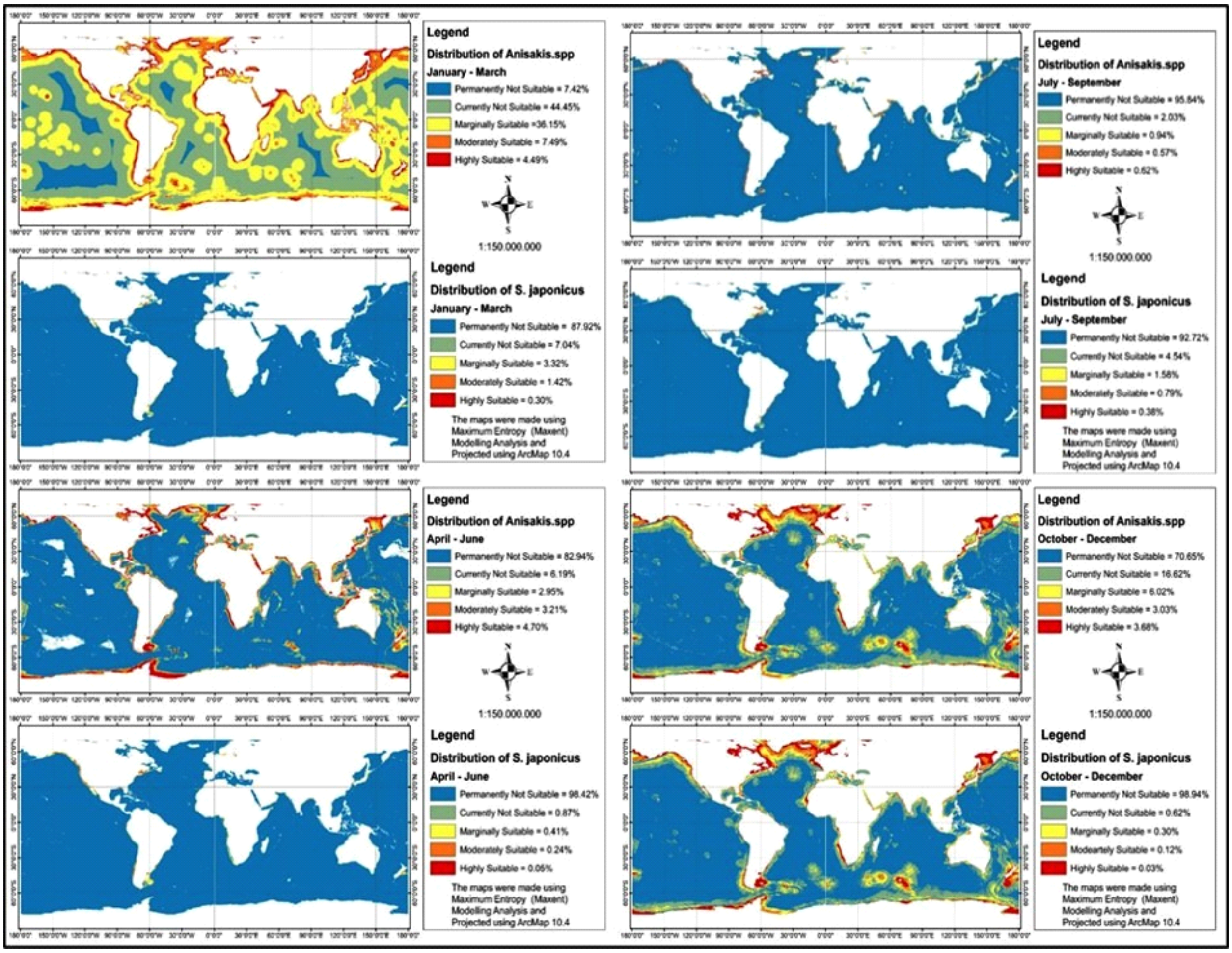

Figure 5. Habitat suitability model of *Anisakis* spp. and *S. japonicus* from seasonal environmental factors.

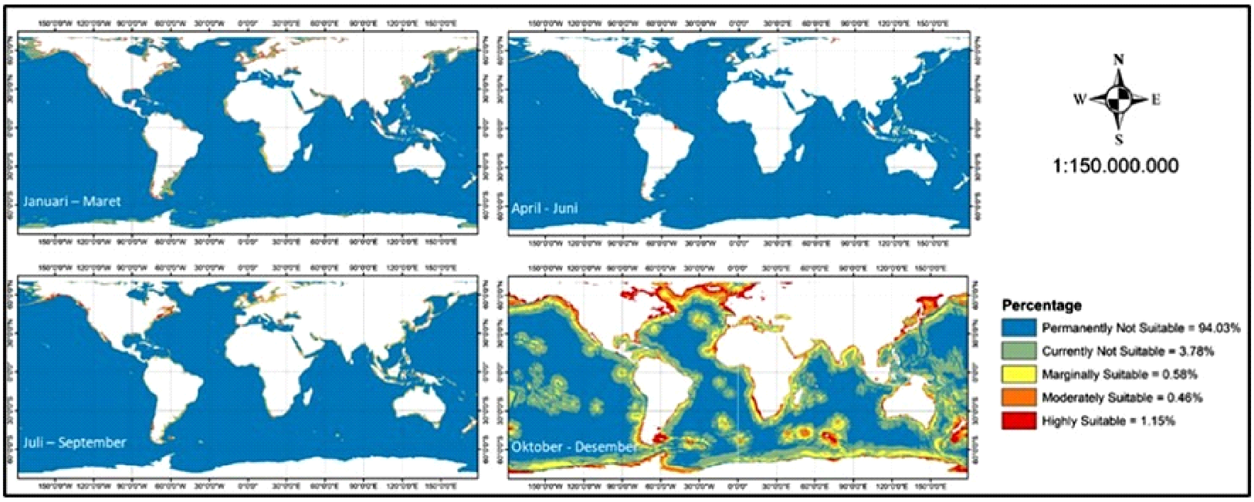

Figure 6. Spatio-seasonal habitat suitability model of *Anisakis* spp. infestation in *S. japonicus.*

Table 3. Indonesian imports of *S. japonicus* from 2017 to 2022

Country	Import Weight (000 kg)						Summary
	2017	2018	2019	2020	2021	2022	
China	72,260,205	56,960,976	32,836,282	13,571,195	28,317,756	29,541,974	233,488,389
Japan	7,038,374	2,238,057	971,731	2,534,396	3,042,291	3,765,171	19,590,021
Norway	3,798,944	4,134,833	2,392,700	2,417,540	5,867,080	0	18,611,097
Iceland	201,760	1,101,570	1,535,905	1,022,000	1,510,249	714,752	6,086,236
United Kingdom	0	75,000	1,310,000	524,000	104,800	2,799,280	4,813,080
Netherland	674,100	324,054	216,000	378,000	1,412,880	1,124,460	4,129,494
Local (Indonesia)	756,708	830,523	15,625	0	0	0	1,602,856
South Korea	142,368	99,988	171,571	84,111	220,643	127,380	846,060
Singapore		335,000	45,120	0	0	0	380,120
Saudi Arabia	200,000	0	0	0	0	0	200,000
Australia	0	162.000	0	0	0	0	162,000
Malaysia	49,852	46,691	49,400	0	0	0	145,943
India	50,000	0	0	0	0	0	50,000
Ireland	0	48,000	0	0	0	0	48,000
Taiwan	0	0	0	48,000	0	0	48,000
Canada	11,550	5,625	6,000	0	5,625	0	28,800
Total (000 kg)	85,183,862	66,362,317	39,550,334	20,579,242	40,481,324	38,073,018	
Valuation (Rp. 000)	1,080,405,425	740,283,198	514,121,589	384,136,991	709,337,641	675,687,454	

Source: The Fish Quarantine Inspection Agency (2022)

and Zuraya 2018), even though the businesses were producing uncontaminated canned fish.

China, Japan, and Norway are the biggest exporting countries of *S. japonicus* to Indonesia. China is the major contributor, supplying 233 thousand tons over the last six years, with an average of 39 thousand tons annually. On the other hand, imports from the other two countries ranged from 18-19 thousand tons over the same period, with an average of 3.1-3.2 thousand tons per year. The habitat suitability model shows that China and Japan provided suitable habitats for *Anisakis*' infestation in *S. japonicus*, especially during each year's first and fourth quarters. Therefore, it is crucial to implement robust measures and regulations to address the potential risks of importing parasite-infested *S. japonicus* from China and Japan.

Table 4. Number of import batch inspections conducted by the Fish Quarantine Inspection Agency for *S. japonicus* from 2017 to August 2022

Variable Observed	2017		2018		2019		2020		2021		2022		Total	(+) record in 6 years
	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)	(+)	(-)		
Bacteria	0	35	0	91	0	149	0	108	0	125	0	185	693	0
Fungus	0	295	0	265	0	84	0	0	0	2	0	0	646	0
Chemical Quality	0	529	1	317	0	298	0	184	0	351	0	499	2179	1
Microbial Quality	0	1	0	265	1	478	0	1215	1	2085	5	4242	8293	7
Organoleptic Quality	0	0	0	96	0	463	3	319	14	478	10	644	2027	27
Parasite	0	4	4	165	0	148	0	90	6	158	0	172	747	10
Virus	0	1235	13	1088	1	908	0	591	2	731	0	0	4569	16
Combined Parasite, Bacterial, Fungus, Virus, Enzyme, Hormone, and Protein	0	0	0	0	0	0	0	0	0	941	2	2407	3350	2
Total sample	0	2099	18	2287	2	2528	3	2507	23	3930	15	5742	22504	63

As part of the monitoring program for the imported fish product, the Indonesian Fish Quarantine and Inspection Agency (FQIA) performed 22,504 tests for imported *S. japonicus* from 2017-2022 (Table 4). The significant parameters tested were microbiological analysis, viruses, and a combination of all analytical parameters required by the fish industries. Parasite testing is not a mandatory variable required by the industries; therefore, specific parasite testing only accounted for 747 batches, with ten batches testing positive. Despite having a low prevalence (10 out of 747) in the last six years, this vulnerability can be avoided by more extensive batch sampling, especially at temporal times when environmental conditions are suitable for *Anisakis* spp. infestations to *S. japonicas.*

In the European Union, Anisakis infestation in fish is reported through the rapid alert system for food and feed (RASFF). The competent authorities implement various measures regarding the notifications of Anisakis infestation in imported fish, such as destruction and market withdrawal (Caldeira et al. 2021). However, Indonesia lacks such a reporting system. Moreover, mandatory zoonotic parasite testing is not in place, leading to the scarcity of actual figures of Anisakis' infestation in imported fish in Indonesia. Given that Anisakis infection is mainly associated with consuming raw or undercooked fish, official market controls should be complemented by implementing standardized and more sensitive methods for parasite detection.

Based on our spatio-temporal prediction model analysis, we suggest testing zoonotic parasites on imported fresh and/or frozen fish products as a mandatory assay in the existing national quality and safety requirements for fresh fish (SNI 2729:2013). The assay is particularly needed between the end of QIV and Q1 of each year, based on the predicted ecological correspondence of parasite occurrence and fish catchment to the environmental condition. Further research is necessary to validate the seasonal data and develop habitat suitability model software, facilitating stakeholders in monitoring and supervising the quality of fish products. Such software could assist the stakeholders as a rapid warning system to control the spread of *Anisakis*' infestation and to avoid further anisakiasis infection. The Indonesian Ministry of Marine Affairs and Fisheries, the Indonesian Ministry of Health, and relevant entrepreneurs would greatly benefit from this innovation by ensuring the quality and safety of fish products and protecting public health.

Conclusion

The infestation of *Anisakis* spp. to *S. japonicus* has been detected through several environmental predictors, including sea surface temperature, diffuse attenuation coefficient, depth, and distance to terrestrial. The habitat suitability model indicated spatio-temporal dynamics of this parasite infestation, with higher occurrence predicted in each year's first and fourth quarters.

Based on the data on fish importation and inspection of imported fish to Indonesia, it is recommended to introduce a zoonotic parasites test as a mandatory requirement for fresh fish, complementing the national standard SNI 2729:2013, and further importation strategy by the government and fish industries. This proposed SNI revision and the importation strategy aimed to address the *Anisakis'* infestation in *S. japonicus*, thus protecting the consumer and the canned fish industry. Further research is needed to validate the seasonal data and refine the habitat suitability model. This effort should include developing software that can facilitate stakeholders in effectively monitoring and controlling the quality of fish products. This software would serve as a rapid warning system, enabling the timely detection of potential anisakiasis infection and facilitating preventive measures to prevent the spread of anisakiasis allergens.

Overall, by incorporating zoonotic parasite testing, validating seasonal data, and implementing advanced software solutions, Indonesia can establish a proactive and comprehensive approach to monitor and mitigate the risks associated with parasitic infestations. Such measures will contribute to ensuring the safety and quality of fish products while protecting public health.

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Supplementary Materials

Supplementary materials is not available for this article.

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