UNIVERSITI PUTRA MALAYSIA

CHARACTERIZATION OF SPAWNING AND NURSERY GROUNDS OF HILSA, Tenualosa ilisha (HAMILTON 1822) BASED ON LARVAL AND JUVENILE DISTRIBUTION AND FEEDING HABITS

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

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MD. HARUNOR RASHID

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Hilsa (*Tenualosa ilisha*) is a migratory fish within the Bay of Bengal region and is mostly harvested from the waters of Bangladesh. The Meghna River is the main corridor for hilsa migration from Bay of Bengal of Bangladesh which provides the major habitat for spawning and movement migration. The abundance of hilsa in Meghna River varies from year to year and the knowledge of the effect of environmental factors on distribution and abundance of hilsa larvae and juveniles in the Meghna River still now absent. Hence, the study was conducted to characterize the spawning and nursery grounds of hilsa based on larva and juvenile distribution in relation to environmental parameters in the Meghna River and its tributaries in Bangladesh. A total of nine sampling stations from August 2017 to January 2018 for hilsa larvae and 18 sampling stations for hilsa juveniles from February to April 2017 were surveyed monthly using bongo net (mouth diameter of 50 cm with 400 µm of mesh size) and experimental net (2.5, 3.5, 4.5 and 5.5 cm of mesh sizes), respectively. The environmental parameters i.e., water temperature (ºC), salinity (‰), dissolved oxygen (DO in mg/L), pH (1-14), conductivity (µS/cm); total dissolved solids (TDS in mg/L) and rainfall (mm) data were recorded monthly from the selected areas.

The study showed that the highest mean larvae density (37.77 ± 5.64 ind. m^{-3}) was observed in lower parts followed by the middle (33.07 ± 10.27 ind. m^{-3}) and it was absent in upper stretches of the river. The abundance of hilsa larvae were statistically similar ($p > 0.05$) in lower and middle stretches but was significantly different ($p < 0.05$) compared to the upper stretches of the Meghna River. The highest mean larvae density was observed in September 2017 (61.07 ± 15.56 ind. m^{-3}), where it could not be found in January 2018. The abundance of hilsa larvae in the Meghna River was statistically similar ($p > 0.05$) in the months of September, October, and November, but the abundance was significantly different ($p < 0.05$) from August 2017 and December 2017. Bray-Curtis similarity index and nonmetric multidimensional scaling (nMDS) clearly separated the lower and middle parts from upper stretches of Meghna River and had 77 % similarity in terms of larval abundance.

In the hilsa larvae study, significant variations ($p > 0.05$) of environmental parameters were found among the study zones except for water temperature and rainfall. The water temperature was highest (28.72±1.09 ºC) in the upper and lowest (24.59±1.15 ºC) in the middle zone of the river. Salinity, pH and conductivity were highest as 0.67±0.16 ‰, 7.40±0.07 and 388.16±29.05 µS/cm, respectively in the lower zone and lowest as 00±0.00 ‰, 6.89±0.16 and 226.08±14.57 µS/cm, respectively in the upper zone of the river. DO and TDS were highest as 7.41±0.05 mg/L and 154.71±21.63 mg/L, respectively in the middle and lowest as 6.70±0.27 mg/L and 92.73±14.79 mg/L, respectively in the upper zone of the river. Furthermore, highest rainfall (290.67±99.26 mm) was recorded at upper and lowest (205.03±35.64 mm) from the lower zone of the river. The non-parametric Spearman's correlation analysis showed the larval abundance was greatly influenced ($p < 0.05$) by temperature, DO, pH and TDS. Principal component analysis (PCA 1, PCA 2 and PCA 3) showed that temperature, salinity, DO, pH, and conductivity explained 83.5% of the larvae variations in the study areas. However, biotic-environmental (BIO-ENV) analysis showed that water temperature, salinity, and pH played significant role ($p < 0.05$) in the hilsa larval distribution.

On the other hand, the highest mean juvenile abundance was found in the middle river stretch (58.33 ± 14.64 ind./100 m net/30 min), followed by the lower (27.39 ± 6.03 ind./100 m net/30 min) and upper (2.17 ± 0.78 ind./100 m net/30 min) stretches of the river. There were significant differences in juvenile abundances ($p < 0.05$) among the study areas. However, no significant differences ($p > 0.05$) of juvenile abundance were observed among the months during the study period. Bray-Curtis similarity index indicated the lower, middle, and upper stretches of the river had only 46 % similarity in terms of juvenile hilsa distribution.

In the hilsa juvenile study, salinity showed significant variations ($p > 0.05$) among the zones. The highest (1.34±0.29 ‰) salinity was recorded from lower and lowest (00±0.00 ‰) in the upper zone of the river. Temperature, pH, DO, conductivity, TDS and rainfall did not show variations ($p < 0.05$) among the zones. The non-parametric Spearman's correlation analysis showed the juvenile abundance was significantly ($p < 0.05$) correlated with salinity, pH, and TDS. Principal component analysis (PCA 1, PCA 2 and PCA 3) showed that temperature, salinity DO, pH and TDS explained 75.7% of the hilsa juvenile variations in the study areas. However, biotic-environmental (BIO-ENV) analysis showed juvenile distribution was highly dependent on salinity ($p < 0.05$).

The study also revealed that phytoplankton including Bacillariophyceae (eleven genera), Chlorophyceae (four genera), Cyanobacteria (six genera) and Euglenophyceae (two genera), and zooplankton including Protozoa (three genera), Rotifera (seven genera), Copepoda (five genera), Cladocera (five genera), Ostracoda (one genus) and Chaetognatha (one genus) were observed in the juvenile gut analysis. The juvenile gut content also showed that phytoplankton and zooplankton formed 91 % and 4 % of the total food, respectively, indicating that hilsa juveniles were highly dependent on phytoplankton.

Therefore, habitat location, time, feed availability and environmental parameters influenced the distribution of hilsa in the study area.

The study illustrated information on hilsa larva and juvenile distribution in relation to environmental parameters could provide important evidence for locating major hilsa spawning and nursery areas to effectively protect this important resource in Bangladesh waters.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENCIRIAN KAWASAN PENELURAN DAN TAPAK SEMAIAN HILSA, *Tenualosa ilisha* (HAMILTON 1822) BERDASARKAN TABURAN SERTA TABIAT PEMAKANAN LARVA DAN JUVANA

Oleh

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Terubok (*Tenualosa ilisha*) adalah ikan yang bermigrasi di wilayah Teluk Bengal dan kebanyakannya dituai dari perairan Bangladesh. Sungai Meghna adalah koridor utama penghijrahan terubok dari Teluk Bengal Bangladesh yang menyediakan habitat utama untuk penghijrahan dan migrasi pergerakan. Kelimpahan terubok di Sungai Meghna berbeza dari tahun ke tahun dan pengetahuan mengenai pengaruh faktor persekitaran terhadap taburan dan banyaknya larva dan juvenil di sungai Meghna adalah terhad pada masa kini. Oleh itu, Kajian ini dilakukan untuk mencirikan kawasan pembiakan dan asuhan terubok berdasarkan taburan larva ikan dan ikan juvenil berkaitan dengan faktor persekitaran di sungai Meghna dan anak sungai di Bangladesh. Sebanyak sembilan stesen persampelan dari bulan Ogos 2017 hingga Januari 2018 untuk larva terubok dan 18 stesen persampelan untuk ikan juvenil terubok dari Februari hingga April 2017 telah dipilih kajian setiap bulan menggunakan jaring Bongo (diameter mulut jaring 50 cm dengan saiz mesh 400 µm) dan jaring eksperimen (2.5, 3.5, 4.5 dan 5.5 cm saiz mesh). Parameter persekitaran iaitu suhu air (°C), kemasinan (‰), oksigen terlarut (DO dalam mg/L), pH (1-14), konduktiviti (µS/cm); jumlah pepejal terlarut (TDS dalam mg/L) dan taburan hujan (mm) dicatatkan setiap bulan dari kawasan yang dipilih. Kajian menunjukkan bahawa nilai purata larva tertinggi (37.77 ± 5.64 ind. m^{-3}) diperhatikan di bahagian hilir sungai diikuti oleh bahagian tengah sungai (33.07 ± 10.27 ind. m^{-3}) , tetapi larva terubok tidak didapatidi bahagian hulu sungai. Tiada perbezaan ($p > 0.05$) kelimpahan larva hilsa secara statistik antara bahagian hilir dan tengah sungai, tetapi mempunyai perbezaan ($p < 0.05$) dengan hulu sungai Meghna. Nilai purata larva tertinggi diperhatikan pada bulan September 2017 (61.07 ± 15.56 ind. m^{-3}), sementara tiada larva dapat dijumpai pada bulan Januari 2018. Larva terubok terdapat dengan banyaknya di sungai Meghna dengan tiada perbezaan statistik ($p > 0.05$) pada bulan September, Oktober dan November, tetapi jumlahnya jauh berbeza ($p < 0.05$) dari Ogos 2017 dan Disember 2017. Indeks kesamaan Bray-Curtis dan penskalaan multidimensi nonmetrik (nMDS) secara jelas memisahkan bahagian hilir dan tengah sungai dari bahagian hulu sungai Meghna dan mempunyai persamaan 77 % dari segi kelimpahan terubok larva.

Dalam kajian terubok larva, terdapat variasi yang signifikan ($p > 0.05$) parameter persekitaran di antara zon kajian kecuali suhu air dan taburan hujan. Suhu air tertinggi (28.72 ± 1.09 ^{o}C) di bahagian atas dan terendah (24.59 ± 1.15 ^{o}C) di zon tengah sungai. Kemasinan, pH dan konduktiviti tertinggi adalah 0.67 ± 0.16 ‰, 7.40 ± 0.07 dan 388.16 ± 29.05 µS/cm, masing-masing di zon bawah dan terendah sebagai 00 ± 0.00 ‰, 6.89 ± 0.16 dan 226.08 ± 14.57 µS/cm, masing-masing di zon atas sungai. Oksigen terlarut dan jumlah pepejal terlarut tertinggi masing-masing 7.41 ± 0.05 mg/L dan 154.71 ± 21.63 mg/L, di tengah dan terendah 6.70 ± 0.27 mg/L dan 92.73 ± 14.79 mg/L masing-masing di zon atas sungai. Selanjutnya, taburan hujan tertinggi (290.67 ± 99.26 mm) dicatatkan di bahagian atas dan terendah (205.03 ± 35.64 mm) dari zon bawah sungai. Analisis korelasi Spearman bukan parametrik menunjukkan kelimpahan larva sangat dipengaruhi ($p < 0.05$) oleh suhu air, oksigen terlarut, pH dan jumlah pepejal terlarut. Analisis komponen utama (PCA 1, PCA 2 dan PCA 3) menunjukkan bahawa suhu air, kemasinan, oksigen terlarut, pH dan konduktiviti menjelaskan 83.5 % bagi variasi larva di kawasan kajian. Namun, analisis biotik-lingkungan (BIO-ENV) menunjukkan bahawa suhu air, kemasinan, dan pH memainkan peranan penting ($p < 0.05$) dalam taburan terubok larva.

Sebaliknya, kelimpahan secara purata ikan juvenil tertinggi dijumpai di bahagian tengah sungai (58.33 ± 14.64 ind./100 m net / 30 min) diikuti oleh yang bahagian hilir sungai (27.39 ± 6.03 ind./100 m net / 30 min) dan bahagian hulu sungai (2.17 ± 0.78 ind./100 m net / 30 min). Terdapat perbezaan yang signifikan bagi jumlah ikan juvenil ($p < 0.05$) antara kawasan kajian. Walau bagaimanapun, tiada perbezaan yang signifikan ($p > 0.05$) kelimpahan ikan juvenil antara bulan selama tempoh kajian. Indeks kesamaan Bray-Curtis menunjukkan hilir, tengah dan hulu sungai hanya mempunyai persamaan 46 % dari segi taburan ikan juvenil.

Dalam kajian juvenil terubok, kemasinan menunjukkan variasi yang signifikan ($p > 0.05$) di antara zon. Kemasinan tertinggi (1.34 ± 0.29 ‰) dicatat dari bawah dan terendah (00 ± 0.00 ‰) di zon hulu sungai. Suhu air, pH, oksigen terlarut, konduktiviti, jumlah pepejal terlarut dan taburan hujan tidak menunjukkan variasi ($p < 0.05$) di antara zon. Analisis korelasi Spearman bukan parametrik menunjukkan kelimpahan juvenil ikan secara signifikan ($p < 0.05$) berkorelasi dengan kemasinan, pH, dan pepejal terlarut (TDS). Analisis komponen utama (PCA 1, PCA 2 dan PCA 3) menunjukkan bahawa suhu air, kemasinan, oksigen terlarut, pH dan jumlah pepejal terlarut menjelaskan 75.7% variasi juvenil terubok di kawasan kajian. Walau bagaimanapun, analisis biotik-persekitaran (BIO-ENV) menunjukkan taburan juvenil ikan sangat bergantung kepada kemasinan ($p < 0.05$).

Kajian itu juga mendedahkan bahawa fitoplankton termasuk Bacillariophyceae (sebelas genus), Chlorophyceae (empat genus), Cyanobacteria (enam genus) dan Euglenophyceae (dua genus), dan zooplankton termasuk Protozoa (tiga genus), Rotifera (tujuh genus), Copepoda (lima genus), Cladocera (lima genus), Ostracoda (satu genus) dan Chaetognatha (satu genus) diperhatikan dalam analisis usus ikan juvenil. Kandungan usus ikan juvenil juga menunjukkan bahawa fitoplankton dan zooplankton merangkumi sebanyak 91 % dan 4 % dari jumlah makanan, menunjukkan bahawa ikan juvenil hilsa sangat bergantung pada fitoplankton. Oleh itu, lokasi habitat, masa, ketersediaan makanan dan parameter persekitaran mempengaruhi terubok di kawasan kajian.

Kajian ini menggambarkan maklumat mengenai taburan larva terubok dan ikan juvenil dengan parameter persekitaran. Ini dapat memberikan maklumat utama yang penting untuk mendapatkan kawasan pembiakan dan asuhan terubok untuk melindungi sumber ini di perairan Bangladesh.

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Thanking you
Md. Harunor Rashid

I certify that an Examination Committee has met on 29 December 2020 to conduct the final examination of Md. Harunor Rashid on his thesis entitled "Characterization of spawning and nursery grounds of hilsa, *Tenualosa ilisha* (Hamilton 1822) based on larval and juvenile distribution and feeding habits" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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Declaration by Members of Supervisor Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIGAs	Alternative Income Generation Activities
ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
BFRI	Bangladesh Fisheries Research Institute
BIO-ENV	Biological Environmental
BoBLME	Bay of Bengal Large Marine Ecosystem
BOBP	Bay of Bengal Program
cm	Centimetre
˚C	Degree Celsius
CPUE	Catch Per Unit Effort
DoF	Department of Fisheries
DO	Dissolved Oxygen
EC	Electrical Conductivity
ECOFISH	Ecosystems Improved for Sustainable Fisheries
FRSS	Fisheries Resources Survey System
g	Gram
HFMAP	Hilsa Fisheries Management Action Plan
MoFL	Ministry of Fisheries and Livestock
mg	Milligram
mm	Millimeter
MSY	Maximum Sustainable Yield
NAOH	Sodium Hydroxide
PCA	Principal Component Analysis
PRIMER	Plymouth Routines in Multivariate Ecological Research

SE	Standard Error
SPSS	Statistical Package for Social Science
TDS	Total Dissolved Solids
VGF	Vulnerable Group Feeding
%	Percentage
>	More than
<	Less than
‰	Parts Per Thousand
%	Percentage

CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

Tenualosa ilisha (Hamilton 1822) is known as hilsa, belonging to the subfamily Alosinae of family Clupeidae, and commonly found in marine, estuarine and freshwater rivers in the Indo-Pacific region. The historical range of the species extended from the Persian Gulf to Bay of Bengal, and exclusively large stocks are found in the Bay of Bengal region (Bhaumik, 2015a). Hilsa fishing is a common open water fishery in Bangladesh, India, and Myanmar, especially in almost all major rivers, estuaries, and seas. The imperative contribution and character performance by hilsa fishery is in the arena of employment, foreign exchange earnings and poverty reduction of the Bay of Bengal region (BOBLME, 2010). As a top hilsa producing country, Bangladesh shares more than 70% (517,198 metric tons) of the global catch in 2018 (DoF, 2018). Hilsa, as a species, is vital source of high valued protein, fat and minerals. Due to its enormous palatability, hilsa has been declared as flag fish of Bangladesh. In fact, it has a significant socio-cultural involvement in the communal environment of Bangladeshi people (Hossain *et al.,* 2019).

Bangladesh bears a linkage of rivers and tributaries, and along with other waterbodies, possesses approximately 4.05 million ha of open water area excluding large coastal shelf and marine water in which river and estuary shares about 853,863 ha (Rahman *et al.*, 2018a). The Meghna River and its tributaries form large and important habitats for hilsa fishery in Bangladesh. The bio-physical features of the Meghna River system are important for the hilsa fishery in terms of providing suitable habitats for fish stocks, distribution and population dynamics and provide critical information for conservation strategies of this important resource.

As a migratory fish, most of the hilsa are congenital of freshwater-estuarine and coastal areas. Hilsa fish lives and becomes mature in the sea, and migrate to the upstream for spawning, feeding and growing purposes. It is an anadromous fish with two ecotypes, as one is fluvial potamodromous and the other is a marine type (Bhaumik, 2016). Otolith microchemistry studies of movement pattern of hilsa specified that the fish travel ubiquitously in all three habitats, i.e., from marine water to freshwater through brackish water (Hoq *et al.,* 2011). By habitat, it is a marine species, but it migrates to the estuary and the river particularly for breeding purposes. Thus, a hilsa inhabits different environments like marine, brackish and freshwaters (Haldar & Amin, 2005; Puvanendran, 2013), though some stocks or races of the species do not migrate (Blaber *et al.,* 2003a; Rahman & Cowx, 2006; Hossain *et al.*, 2016). Hilsa spending their young life stages in fresh and brackish water where juveniles migrate offshore for feeding and nurture to adult sizes. At an age of about one and half years old, adult hilsa migrate upstream to inland freshwater to spawn (Blaber *et al.,* 2005). Juvenile hilsa which is the recruiting phase of hilsa is known as jatka in Bangladesh (Miah *et al*., 2000).

The species spawns all the year round, starting from the upstream and upper reaches of the river to the coast. The uttermost spawning time is during the monsoon, and the positive spawning seems to be related to the lunar cycle (Rahman & Cowx, 2006). The recruitment of hilsa occurs almost continuously, providing the recruitment of juvenile hilsa to the river-marine ecosystem all year round (BOBLME, 2010).

Habitats of hilsa show a wide range of variability in physico-chemical characteristics in relation to seasonal changes. In earlier years, most of Bangladeshi rivers were bounteous with hilsa particularly the major rivers, along with their tributaries. Once hilsa were abundant along the shores of Brahmaputra River in the Tejpur State, India. However, at the present time, almost 1500 km habitat of hilsa in the Brahmaputra River is devoid of hilsa owing to various causes such as declining of clean water streams, siltation, and construction of various structures along the river including dams and embankments for flood control and irrigation projects of the country (Haldar, 2002). In addition, various forms of pollution in the river and its distributaries cause detrimental impacts and obliterate the production of hilsa.

1.2 Problem statements

Hilsa is an immense imperative anadromous migratory fish and inhabit marine-estuarine-riverine systems. Each phase of its life cycle is dependent of the health of the specific habitat along the river-marine gradient (Ahsan *et al.*, 2014). The hilsa population is declining due to overexploitation and habitat changes in Bangladesh waters (Shohidullah, 2015; Hossain, 2017).

The Meghna River is the main corridor for hilsa migration from Bay of Bengal of Bangladesh which provide the major habitat, while juvenile graze in the estuarine area of the river and then migrate to marine environment in the Bay of Bengal as adults (Blaber *et al.* 2003b; Amin *et al.*, 2004; Rahman & Cowx 2006; Ahsan *et al.*, 2014). The hilsa fishery is completely dependent on spawning success, and larval and juvenile recruitment, which in turn are influenced by various environmental factors. Several studies have been conducted on hilsa fisheries and management *viz.* stock assessment (Amin *et al.*, 2004; Mohamed & Qasim, 2014; Rahman *et al.*, 2018); population biology (Amin *et al.*, 2000; Al-Baz, 2001; Amin *et al.*, 2002; Haldar & Amin, 2005); exploitation rates (Amin *et al.*, 2001; 2008; Bala *et al.*, 2014); jatka fishing and sustainability (Miah *et al.*, 1998; Amin *et al.*, 2000; Rahman *et al.*, 2018; Das *et al.*, 2019; Karim *et al.*, 2019). Haldar (2002) observed the oozing males and females of hilsa in the lower parts of Meghna river (Hatiya, Sandwip & Bhola). Based on these studies, Blaber *et al.* (2003b) reported that hilsa spawns in rivers, estuaries and on the coast of Bangladesh waters. Further research to understand new spawning and nursery habitat based on modelling and geographic information systems have been conducted in Bangladesh waters (Hossain *et al.*, 2014a; 2016). However, none has attempted to study the larval and juvenile distribution in Bangladesh for exposing the spawning and nursery habitats in the Meghna River. Abundance of hilsa in Meghna River varies every year and the information of the effect of environmental factors on distribution and abundance of hilsa larvae and juvenile in the river still now absent. This is the first attempt to characterize the spawning and nursery grounds based on the hilsa larval and juvenile distribution in relation to environmental factors in the waters. Moreover, the understanding of food and feeding habits of juvenile hilsa is still poor in the research area. Therefore, the study was undertaken to characterize the spawning and nursery habitats for establishing better management strategies and protocols of the hilsa fishery along the Meghna River in Bangladesh.

1.3 Objectives

The general objective of this study is to obtain relevant information on the migration and distribution of different stages of hilsa fish in terms of space and time in relation to environmental parameters in order to develop effective management strategies in the Meghna River of Bangladesh waters.

The specific objectives of the study are:

i. To determine the spatio-temporal distribution of larvae and hilsa juveniles in the Meghna River and its tributaries.
ii. To determine the relationship between larvae and juvenile abundance, and environmental parameters.
iii. To examine the feeding habits and temporal variations of diets of hilsa juvenile.
iv. To identify and characterize the spawning and nursery grounds of hilsa.

1.4 Hypotheses

For this study, three ecosystems which are upstream, middle, and lower stretches of the Meghna River of Bangladesh were selected to test the following hypothesis:

1. Ho: Larvae and juveniles of hilsa do not show any pattern of spatial-temporal distribution along the river-marine gradient over an annual cycle.
H_A: Larvae and juveniles of hilsa show specific pattern of spatial-temporal distribution along the river-marine gradient over an annual cycle.

2. Ho: There are no relationship between larvae and juvenile abundance, and environmental parameters.
H_A: There are relationship between larvae and juvenile abundance, and environmental parameters.

3. Ho: There are no temporal variations in the diet of hilsa juveniles.
H_A: There are temporal variations in the diet of hilsa juveniles.

4. Ho: There are no specific spawning and nursery grounds of hilsa along the river-marine gradient.
H_A: There are specific spawning and nursery grounds of hilsa along the river- marine gradient.

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