CHAPTER 4
FISHERY DATA ANALYSIS

4.1 Introduction

4.1.1 Quantitative Measures of Elasmobranch Diversity

Elasmobranch, which include sharks, rays, and skates, are important apex predators in marine ecosystems and have a considerable influence on the food chain dynamics in oceanic habitats. The ecological structure of a community, determined by the variety of species present, is a critical measure of the ecosystem's stability and quality. The presence of a wide variety of species within an ecosystem indicates its stability and ability to operate properly. This highlights the importance of gathering specific information on the composition of fish populations in order to create successful management and conservation plans for fisheries ecosystems (Fischer and Quist, 2014). Nevertheless, these species are progressively endangered due to excessive fishing, the deterioration of their habitats, and the impact of climate change. Assessing and examining their diversity is crucial for developing efficient conservation methods and sustainable management techniques. Diversity indices are highly dependable tools for assessing biodiversity within an ecosystem, as they provide quantitative values.

The Gujarat maritime zone supports a varied population of elasmobranchs. Nevertheless, despite the abundance of different elasmobranch species, no quantitative measurements or analysis have been carried out to examine them. Prior research was limited to reports specifically focused on the presence of such occurrences and their impact on the fishing industry. The absence of thorough research creates a void in our awareness of the complete range and well-being of elasmobranch species in the area. In a recent study, Karuppasamy et al. (2020) performed a quantitative analysis on 44 elasmobranch species found in the Wadge Bank region of South India.

4.1.2 Population dynamics and Stock Assessment of *Carcharhinus falciformis*

Accurate and reliable data on population statistics and life history attributes of the exploited species are essential to achieve sustainable fisheries through rational exploitation. Utilizing exploitative patterns as baseline data might enhance the comprehension of population status. While there are existing studies on the fisheries and biology of elasmobranchs in Indian seas, research specifically focused on age, growth, and population dynamics is still sparse. A major obstacle in assessing elasmobranch fishery stocks, impeding successful management initiatives, is the limited focus of fisheries on a small number of elasmobranchs species. Consequently, this group has not received thorough examination in relation to developing efficient management strategies. The focus of most investigations in India was mostly limited to small pelagic and coastal species. Nair (1976) conducted a study on the age and growth of the Spadenose shark *Scoliodon laticaudus* in the waters of Bombay. The study utilized the length frequency approach. Krishnamoorthi and Jagadis (1986) conducted a study on the population dynamics of the Milk shark, *Rhizoprionodon acutus*, in the waters of Madras. Mathew and Devaraj (1997) conducted a study on the population dynamics of the shark species *Scoliodon laticaudus* in the coastal waters of Maharashtra. Devadoss (1998) conducted a study on the growth and population parameters of *Scoliodon laticaudus* from the Calicut coast. In their study, Kasim et al. (1999) examined the age, growth, and mortality of the Spottail shark *Carcharhinus sorrah* in the waters of Tuticorin. Marichamy et al. (1999) conducted a study on the age and growth of the ray species Himantura bleekeri in Tuticorin. Soundararajan and Roy (2004) conducted a study on the age and growth of deep-sea sharks *Centrophorus acus* and Squalus megalops found in the waters of Andaman. Manjusha et al. (2011) examined the population dynamics of the hammerhead shark species *Sphyrna zygaena* along the coast of Kerala. Moorthi and Jagadis (2011) conducted a study on the biology and population dynamics of the *Rhizoprionodon acutus* in the waters of Madras. Manojkumar et al. (2012) examined the population parameters of *Carcharhinus limbatus* along the Malabar Coast. Purushottama et al. (2017) conducted a study on the population dynamics and stock assessment of *Rhizoprionodon oligolinx* in the north-west coast of India. Only a limited number of studies have been undertaken along the Gujarat coast, focusing primarily on small-sized species. Kasim (1991) conducted research on the population dynamics of *Scoliodon laticaudus* and *Rhizoprionodon acutus* in the waters of Gujarat. Sen et al. (2017) conducted a study on the population dynamics and stock assessment of *Rhizoprionodon acutus* along the Gujarat coast of India. Dash et al. (2019) conducted a study on the population dynamics and stock assessment of *Scoliodon laticaudus* along the Gujarat coast of India.

The selection of Carcharhinus falciformis for population dynamics analysis is based on the high fishing pressure on this resource and the little knowledge of its population dynamics and structure (Kizhakudan et al., 2019). Additionally, there is a lack of data regarding the growth and death rates of *C. falciformis* in the Gujarat maritime zone. Age structure and population factors are crucial for developing management strategies to ensure sustained exploitation.

This chapter aims to evaluate the diversity of elasmobranch species using a quantitative method and examine the population dynamics of *C. falciformis* in the maritime zone of Gujarat.

4.2 Materials and Methodology

4.2.1 Diversity Indices

Sampling and Data Collection

During January 2021 to December 2023 Monthly sampling was conducted at designated sampling sites to collect data on elasmobranch species. During the data collection, the species composition and the abundance of individuals caught were recorded.

Data Analysis

Firstly, collected data was classified into four seasons: Winter, Spring, Summer, Autumn. Then after, data underwent statistical analysis using the PAST software (Paleontological Statistics Software Package for Education and Data Analysis). This software was employed to conduct diverse statistical analyses in order to comprehend the patterns and trends in species composition and catch numbers throughout distinct seasons. This methodological approach ensured a thorough and organized process of collecting and analyzing data, which allowed for a strong understanding of the many species of elasmobranchs in the study area.

Indices used in analysis of Diversity of Elasmobranchs

A. **Shannon-Weiner Diversity Index (H'):** It is a measure of species diversity in a community. It is calculated using the formula:

$$H' = -\sum_{i=1}^{S} pi \ln(p_i)$$

Where,

S is the total number of species

pi is the proportion of individuals belonging to the i-th species (i.e., $pi = \frac{ni}{N}$, where ni is the number of individuals of species i and N is the total number of individuals of all species)

B. Dominance(D): It is a measure of species dominance in a community. It quantifies the degree to which a few species dominate the community in terms of abundance. Dominance(D) is calculated as:

$$D = \sum \left(\frac{n_i(n_i - 1)}{N(N - 1)} \right)$$

Where,

n_i is the number of individuals of species i.

N is the total number of individuals of all species.

C. Simpson 1-D (Simpson's Diversity Index): A measure of diversity that considers both species richness and the evenness of species abundances. The index calculates the probability that two individuals randomly selected from a sample will belong to different species. It is expressed as:

$$1 - D = 1 - \sum_{i=1}^{s} \left(\frac{n_i(n_i - 1)}{N(N - 1)} \right)$$

Where,

s is the total number of species.

n_i is the number of individuals of species i

N is the total number of individuals of all species.

D. Evenness_e^H/S: This measure expresses how evenly the individuals are distributed among the different species in a community. The formula used is:

$$E = \frac{e^{H'}}{S}$$

Where,

H' is the Shannon-Weiner Diversity Index.

S is the total number of species.

e is the base of the natural logarithm (approximately equal to 2.7)

E. Margalef's Index (d): It is a measure of species richness that adjusts for the number of individuals in the sample. It is calculated using the formula:

$$d = \frac{S-1}{In(N)}$$

Where,

S is the total number of species.

N is the total number of individuals.

F. SHE analysis: It is a method used in ecological studies to assess community biodiversity and structure by analysing three key components: Species Richness (S), Shannon Diversity (H), and Evenness (E). SHE analysis provides a comprehensive understanding of biodiversity by integrating these three metrics, which helps in evaluating the ecological balance and health of biological communities.

G. Individual Rarefaction: It is a statistical method used to standardize species richness by estimating the number of species expected in a sample of a given season. This technique involves repeatedly resampling the observed data to create a rarefaction curve, which shows the expected species richness for varying seasons.

$$E[S_m] = \sum_{i=1}^{S} \left[1 - \left(\frac{N - n_i}{N}\right)^m\right]$$

Where,

S is the total number of species in the original sample

N is the total number of individuals in the original sample

n_i is the number of individuals of species i in the original sample

m is the number of individuals in the rarefied sample

H. **Taxonomic Distinctness:** It is a measure of the average taxonomic distance between species within a community. It quantifies the biodiversity by considering not just the presence of species, but their taxonomic relationships.

$$\Delta = \frac{\sum \sum_{i<j} W_{ij} X_i X_j}{\sum \sum_{i<j} X_i X_j + \sum_i x_i (x_i - 1)/2}$$

Where,

Wij are weights such that Wij = 0 if I and j are the same species, Wij =1 if they are the same genus, etc. the x are the abundances.

I. **K-dominance:** A k-dominance plot is a graphical representation used in ecology to illustrate the relative abundances of species within a community. The plot displays the cumulative percentage of total abundance accounted for by species, ranked from the most to the least abundant.

4.2.2 Similarity Indices

A. **Cluster analysis:** Cluster analysis was conducted to determine the similarities among the seasons. The hierarchical agglomerative method is the most often employed clustering technique. A tree diagram or dendrogram is used to depict the results, where the x-axis represents the complete set of seasons, and the y-axis defines the level of similarity at which the samples or groups are combined. The dendrogram was generated using the Bray-Curtis coefficient, as proposed by Bray and Curtis in 1957. The coefficient was computed using the following formula:

$$BC_{ij} = 1 - \frac{\sum_{k=1}^{S} | x_{ik} - x_{jk} |}{\sum_{k=1}^{S} | x_{ik} + x_{jk} |}$$

Where,

X_{ik} is the abundance of species k in sample i.

Xik is the abundance of species k in sample j.

S is the total number of species.

B. **NMDS (Non-Metric Multi-Dimensional Scaling)**: Non-metric multidimensional scaling (NMDS) was introduced by Shepard (1962ab) and Kruskal (1964) as a method to determine the similarities or dissimilarities between pairs of things and provide a visual representation, or 'map', illustrating their interrelationships. Ecologists commonly employ NMDS as a visualization tool for data that is derived from species abundances or biomasses. Although NMDS primarily emphasizes ordination through dissimilarity matrices, ecological plots such as dominance plots, geometric abundance class plots, and species area plots can be employed in conjunction with NMDS to offer more understanding of species distributions and community structure.

4.2.3 Population dynamics and Stock assessment of *Carcharhinus falciformis* (Bibron, 1839), Silky shark

The length frequency data of the *Carcharhinus falciformis,* Silky shark for the present study was collected from the designated fishing harbour Veraval, Mangrol, Porbandar and Okha along the Gujarat Coast, India during the period November 2021 to October 2023. Data of July and August months were not recorded due to the seasonal fishing banned implemented by Government of Gujarat. The Total length (TL) of Silky shark were measured from the anterior most part of the body to the end of caudal fin to the nearest centimetre (cm). The length frequency data was classified into 10 cm class interval groups, Length-based population dynamic analysis methods were used in the present study. Monthly length frequency data was analysed using FAO-1CLARM Fish Stock Assessment Tools (FiSATII) software of Gayanilo *et al*. (2005). The parameters of von Bertalanffy growth function (VBGF), asymptotic length (Loo) and growth co-efficient (K) were estimated using ELEFAN1 routing incorporated into the FiSATII Software (Bertalanffy, 1938).

The length frequency data of the *Carcharhinus falciformis*, also known as the Silky shark, was obtained from the Veraval, Mangrol, Porbandar, and Okha along the Gujarat Coast, India. The data collection took place from November 2021 to October 2023. The Government of Gujarat enacted a seasonal fishing ban, resulting in the non-recording of data for the months of July and August. The total length (TL) of the silky shark was determined by measuring the distance from the frontmost part of the body to the tip of the tail fin, rounded to the closest centimeter (cm). The length frequency data was categorized into groups with a class interval of 10 cm. The present study utilized length-based population dynamic analysis methodologies. Monthly length frequency data was analysed using FAO-1CLARM Fish Stock Assessment Tools (FiSATII) software of Gayanilo *et al*. (2005). The FiSATII software, specifically the ELEFAN1 routing, was used to estimate the parameters of the von Bertalanffy growth function (VBGF), namely the asymptotic length (Loo) and growth coefficient (K) (Bertalanffy, 1938).

4.2.3.1 Estimation of Growth Parameters

The pattern of growth of most fish species can be expressed using von Bertalanffy growth equation (VBGF) given as:

$$L_t = L_\infty (1 - e - K (t - t_0)$$

Where,

L_t is the mean length at age t.

L_∞ is the asymptomatic length.

K is the growth coefficient

T_0 is the age at zero length (initial condition parameter)

In the present study three methods have been attempted in order to arrive at a reasonable estimate of growth parameters, employing computer based FiSATII program developed by Gayanilo et al. (2005).

The following methods were used to study the growth of *C. falciformis*.

1. **Electronic Length Frequency Analysis (ELEFAN) method**

The ELEFAN method was initially developed by Pauly and David (1980, 1981) and Pauly (1982) to estimate growth characteristics and mortality in fish populations. It was further enhanced by Brey and Pauly (1986) and Brey et al. (1988). The majority of its implementations are written in BASIC and are specifically tailored for use on microcomputers. The system has undergone significant revisions and expansions, resulting in a full software package that includes several new methods for length-based fish stock evaluation (Gayanilo et al., 1988; Gayanilo and Pauly, 1989). The process of identifying modes (or peaks) is achieved using a mechanism known as "restructuring".

Following the rearrangement of the sample, each length class is associated with either a positive value (peak), a negative value (trough), or a zero value. The contiguous sequences of length intervals with positive values are considered as possible cohorts. The Available Sum of Peaks (ASP) is the total sum of the highest points in each consecutive sequence of positive values across all samples. ELEFAN utilizes the growth model (VBGF) to generate multiple growth curves based on the reconstructed data, using a specific set of user-selected growth parameters. The Explained Sum of Peaks (ESP) is the total sum of all points, both negative and positive, that each curve passes through for a specific set of growth parameters. The optimal combination of parameters will result in a curve that intersects the most peaks and avoids the most troughs, hence achieving the largest ESP value. The ESP/ASP ratio can vary from a negative value to one, depending on the data. Higher values suggest a stronger match, and the goodness of fit index (Rn) is defined as:

$R_n = 10_{ESP}/_{ASP}/10$

2. Shepherd's Method (Shepherd, 1987)

The Shepherd's approach bears resemblance to ELEFAN I since it aims to optimize a non-parametric scoring function. There are two alternatives for determining the optional values of L∞ and K: The display and operations of response surface analysis and scan of K-values are very similar to the ELEFAN I routine.

The score Shepherd's method is defined by:

$$S = (S_A{}^2 + S_B{}^2)^{1/2}$$

Where S_A and S_B are the goodness-of-fit scores (S_{tz}) obtained with the derivation of the VBGF in calendar time (t_z) set to 0 and 0.25, respectively.

S_{tz} is defined by:

$$S_{tz} = \sum T_i \cdot \sqrt{Ni}$$

Where,

N_i = frequency for length group i,

T_i = D · cos 2π (t-ti),

D = (sinπ (Δt) / π (Δt)),

$t = \Delta t/2$,

$\Delta t = t_{max} - t_{min}$,

$ti = tz - (1/K) \cdot In(1-(Li/L\infty)$, and

$tz = (1/2\pi) \cdot tan^{-1}(S_B/S_A)$

3. Powell-Wetherall Plot (Powell, 1979; Wetherall, 1986)

This method allows estimation of L_∞ and Z/K from a sample representing a steady-state population, as can be approximated by pooling a time series of length frequency data.

$$(\bar{L} - L') = a + b \cdot L'$$

Where,

$$\bar{L} = \left(\frac{L_\infty + L'}{1 + (Z/K)}\right)$$

From which,

$$L_\infty = -a/b,$$

$$Z/K = -(1+b)/b$$

In FiSATII, the determination of the cut off length (L') is made easier by an adjacent graph (pseudo-catch curve) from which L' may often be identified. The cutoff length can be determined by directly using a mouse pointing device on the Powell-Wetherall plot or by utilizing the pseudo-catch curve to estimate $L\infty$ and Z/K, or by just relying on the pseudo-catch curve. This strategy should be employed exclusively when an ample number of samples are accessible.

4.2.3.2 Mortality Parameters

The factors used to quantify the rate of death are referred to as "mortality parameters". The total mortality rate of cohort Z is the combined sum of the instantaneous rate of fishing mortality F, which results from fishing activities, and the instantaneous rate of natural mortality M, which encompasses deaths caused by factors such as lack of food, competition, predation, and old age, excluding fishing.

1. Estimation of Total Mortality: Estimating Z necessitates either understanding the growth factors of a stock or having knowledge of the age of at least a few fish. Estimating the total instantaneous rate of mortality Z is essential in fish stock assessment as it allows for a better understanding of the dynamics of fish populations that are being fished. Given knowledge of the population's distribution, estimating Z can be achieved using a straightforward method. Multiple techniques are accessible for determining Z by utilizing growth characteristics in conjunction with length–frequency data. The instantaneous rate of total mortality (Z) was determined using the length converted catch curve approach, as described by Pauly (1984, 1990).

Length Converted Catch Curve Method: The method essentially consists of a plot of the natural logarithm of the number of fish in various age groups (Nt) against their corresponding age (t), which gives the linear relationship.

$$Ln\ (Ni/Dti) = a + b\ X\ ti$$

Where,

Ni = the number of fish in length class i,

Dti = the time needed for the fish to grow through length class i,

ti = the age (or the relative age, computed with to = 0) corresponding to the mid length of class i,

b = with sign changed is an estimate of Z.

2. Natural Mortality Estimation: In fish stock assessment, natural mortality is the most difficult parameter to be estimated. The instantaneous rate of natural mortality (M) was estimated by Pauly’s empirical formula (Pauly, 1980 b, 1984).

Pauly’s Empirical Formula: Pauly (1980 b) established relationship of growth parameters L_∞ (in cm) or W_∞ (in g) and K (year^{-1}), mean annual habitat temperature (T in °C) and natural mortality. The equation used was:

$$\log(M) = -0.0066 - 0.279\log(L\infty) + 0.6543\log(K) + 0.4634\log(T)$$

where,

$L\infty$ is the asymptomatic length.

K is the VBGF growth constant

T = the mean annual habitat temperature in °C.

The mean annual habitat temperature was 23 °C.

4.2.3.3 Exploitation Rate (E)

The exploitation rate (E) is defined as the fraction of a year class recruits i.e., caught during all the years of its existence (Ricker, 1975). It is estimated as,

$$E = F / Z$$

4.2.3.4 Probability of capture (Pauly, 1984a)

The mesh size can be suitably regulated to increase the probability of capture. This length or age is designated, as Lc or tc is the length or age at which 50% of the fishes become vulnerable to the gear in question. It happens to be one of the important parameters for the estimation of Yw / R for Beverton and Holt's yield-per-recruit model. It is necessary to find out various probabilities of catching 25%, 50%, and 75% of fish entering the net for selection ogive method, which gives more realistic results (Sparre, 1993). Accordingly, the number of fish that would have been caught is estimated first by backward extrapolation of converted catch curve used for the estimation of Z by Pauly (1980a). The Lc25, Lc50 and Lc75 were estimated from gear selection curve generated from the probability of capture out of which the Lc50 values were used for the further calculations. These parameters were estimated by following Pauly (1984) employing FiSATII.

4.2.3.5 Recruitment pattern and virtual population analysis (VPA)

Seasonal pattern of recruitment is assessed by backward projection, along a trajectory defined by the VBGF of the frequencies into the time axis of a time series of samples (Pauly, 1983). This model relies on two assumptions: firstly, that all fish in the sample exhibit growth patterns characterized by a single set of growth parameters, and secondly, that there is always zero recruitment in one out of the twelve months. Restructured data has been utilized to minimize the temporal dispersion, resulting in a more accurate representation of the recruitment seasonality. The recruitment pattern was analyzed by examining recruitment curves using the final estimated values of L∞, K, and t0. The estimation of longevity was calculated using the formula tmax = 3/K + t0, using the approach developed by Pauly (1983).

Length structured virtual population analysis (Pauly, 1984): This routine provides information on survivors, natural mortality, and fishing mortality in each length group. The initial step is to estimate the terminal population (Nt) given the inputs from following equation:

$$N_t = \frac{C_t.(M + F_t)}{F_t}$$

Where,

C_t = the terminal catch

4.2.3.6 Relative Yield/Recruitment (Y/R) and Biomass/Recruitment (B/R) Analysis

Using knife-edge selection, relative yield-per-recruit (Y'/R) was computed from:

$$^{Y}/_{R} = EU\ ^{M}/_{K}\,(1 - (^{3U}/_{1+m}) + (^{3\ U\ 2}/_{1+2M}) - (^{3\ U\ 3}/_{1+3M})$$

Where,

$$U = 1 - \left(^{L_c}/_{L_\infty}\right)$$

$$m = \frac{1 - E}{\frac{M}{K}} = \left(\frac{k}{Z}\right)$$

$$E = \frac{F}{Z}$$

Relative biomass-per-recruit (B'/R) is estimated from the relationship.

$$\frac{B'}{R} = \frac{\frac{Y'}{R}}{F}$$

While E_{max}, E_{10} and E_{50} are estimated by using the first derivative of this function.

In FiSAT package, E_{max}' represents the exploitation rate which produces maximum yield.

The yield isopleth diagram was generated by plotting iso-values of Y'/R, with varying exploitation ratios (E) on the X-axis and different sizes at initial capture, represented by Lc/L∞ ratios, on the Y-axis.

The process generates plots of Y'/R vs. E = (F / Z) and B'/R vs. E. These plots are used to estimate Emax (the exploitation rate that maximizes yield), E10 (the exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E=0), and E50 (the value of E at which the stock has been reduced to 50% of its unexploited biomass).

4.3 Results

4.3.1 Diversity Indices

Diversity indices were calculated from the fish abundance matrix. Monthly data collected from designated sampling sites were pooled by season and used for further analysis. The indices calculated included the Shannon Wiener diversity index (H'), Simpson diversity index, Margalef richness index (d), Evenness index (J'), Dominance (D), SHE analysis, Individual Rarefaction, and Taxonomic distinctness, all in relation to different seasons.

As indicated by the Shannon - Wiener diversity the index, highest diversity was observed in Spring season (2.74) followed Autumn (2.15), Winter (1.91) and Summer (1.29) (Fig. 4.1).

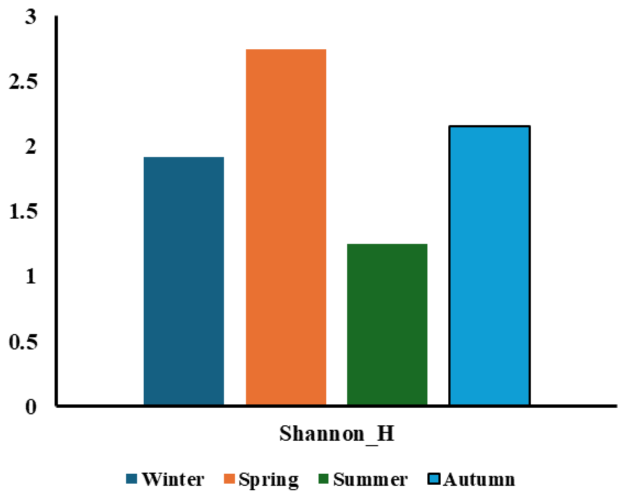

Figure 4.1: Shannon - Wiener diversity index (H) for different seasons

The Dominance (D) values indicate varying levels of species prevalence across seasons. Spring shows the lowest dominance (0.121), Winter (0.257) and autumn (0.251) exhibit moderate dominance, Summer has the highest dominance (0.426) (Fig. 4.2). The Simpson's Index of Diversity (1 - D) results show that spring has the highest diversity (0.87), indicating a very even distribution of species. Winter (0.74) and autumn (0.74) also exhibit moderate to high diversity. Summer, however, has the lowest diversity (0.57) (Fig. 4.3).

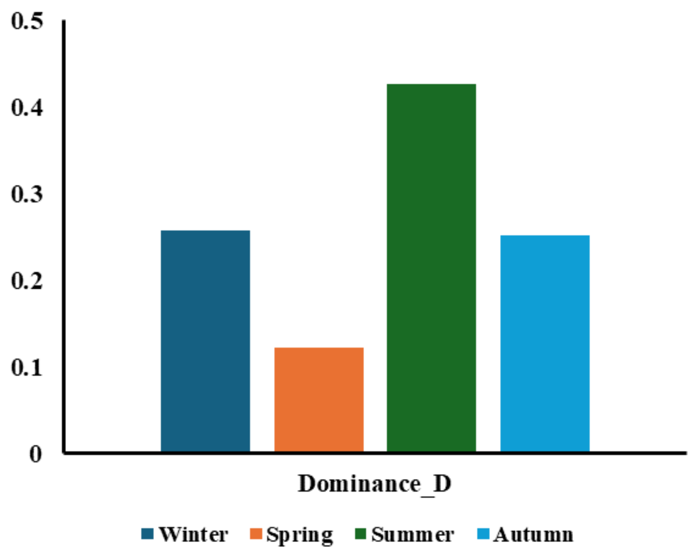

Figure 4.2: Dominance index for different seasons

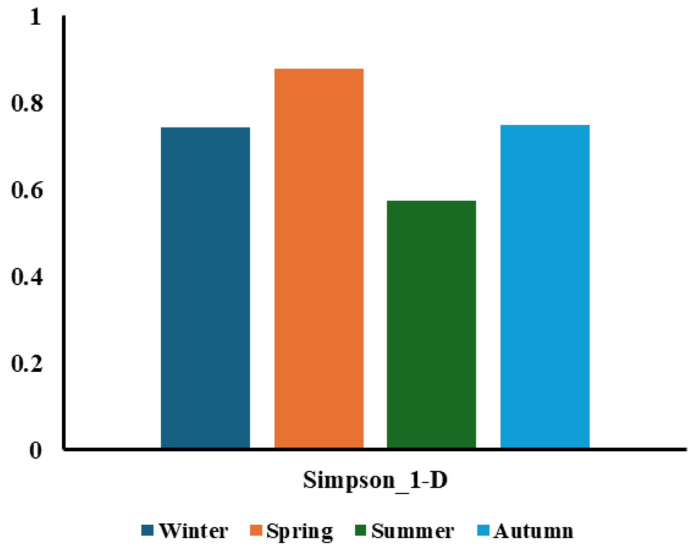

Figure 4.3: Simpson index for different seasons

The Margalef richness index, the highest species richness was observed in the Spring season (5.523), followed by Autumn (4.807), Winter (3.408), and the lowest richness was observed in Summer (1.961) (Fig. 4.4). The Evenness index shows, the most even distribution of species was observed in the Spring season (0.36), Winter follows with an evenness value (0.29) Summer and Autumn exhibit similar and lower evenness values (0.24) and (0.24), respectively (Fig. 4.5).

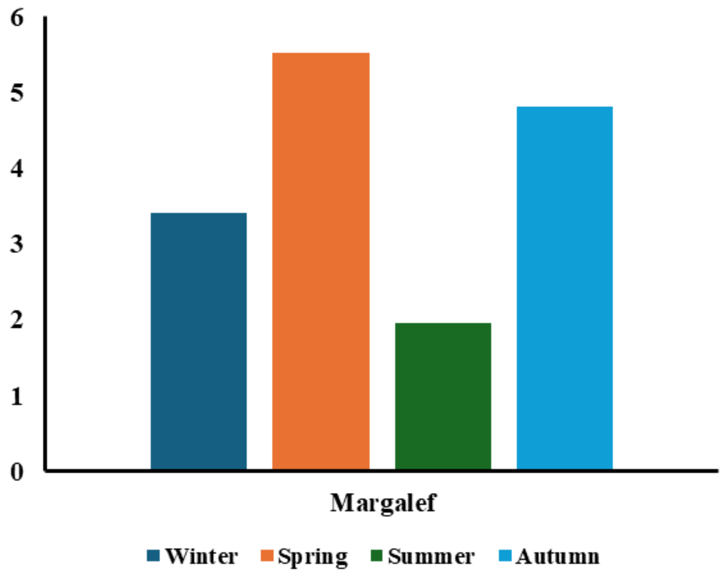

Figure 4.4: Margalef richness index (d) for different seasons

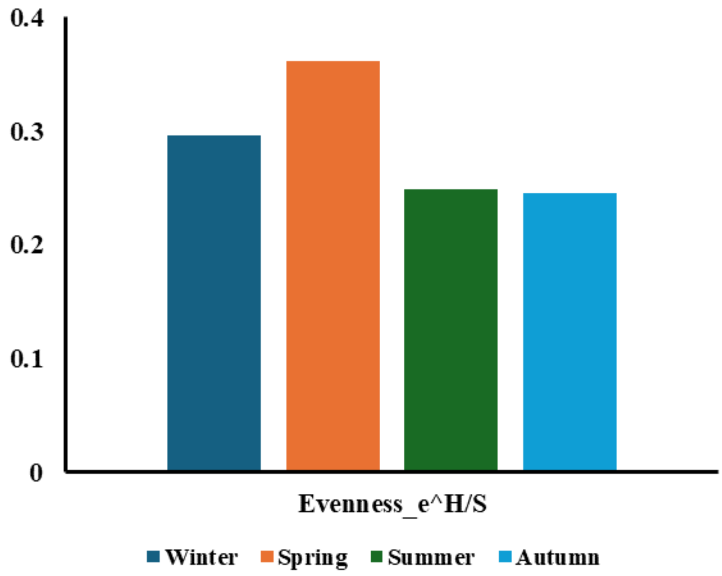

Figure 4.5: Evenness index for different seasons

The SHE analysis graph shows that species richness (ln S) steadily increases with more samples. The Shannon-Wiener diversity index (H) rise initially, stabilize around 2500 samples, and then slightly declines or remains constant. Evenness (ln E) remains consistently low (Fig. 4.6).

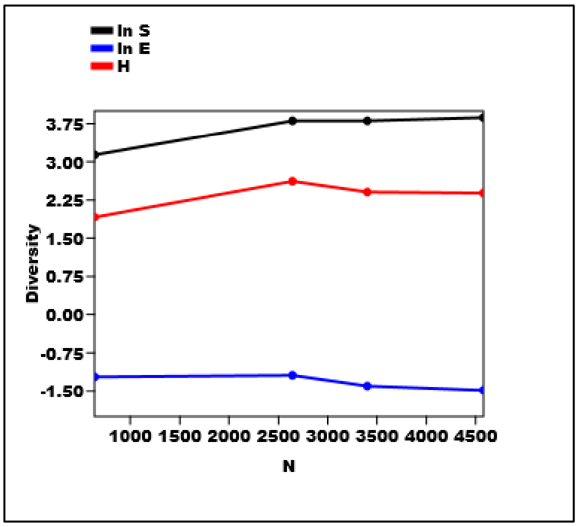

Figure 4.6: SHE analysis

The individual rarefaction analysis indicates that spring has the highest species richness, with its curve reaching the greatest number of taxa and showing a rapid initial increase. Autumn follows with slightly lower species richness, while winter shows moderate richness with a slower initial rise. Summer has the lowest species richness, with its curve rising slowly and levelling off the earliest (Fig. 4.7).

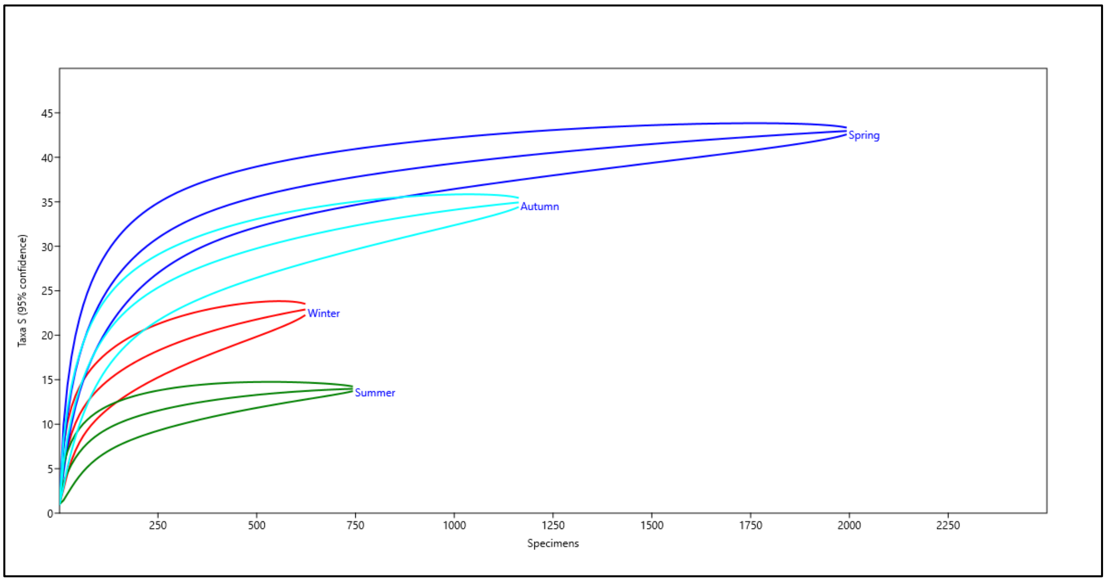

Figure 4.7: Individual Rarefaction

Taxonomic distinctness (Fig. 4.8) indicates Spring has the highest diversity (1.565) and taxonomic distinctness (1.782). Autumn also shows comparatively high values for diversity (1.325) and taxonomic distinctness (1.77) then winter and summer, Winter presents moderate diversity (1.154) and taxonomic distinctness (1.552), and Summer has the lowest diversity (0.718) and taxonomic distinctness (1.25).

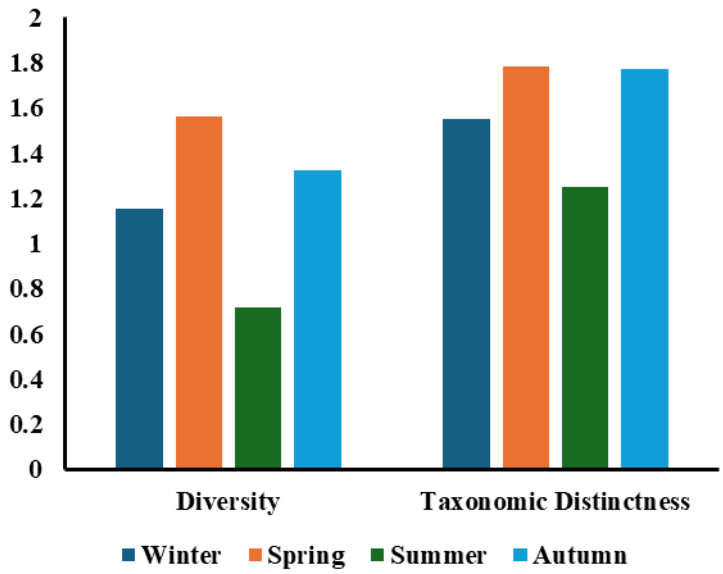

Figure 4.8: Taxonomic distinctness for different seasons

The K - Dominance plot (Fig. 4.9) shows that curve for summer reaches 100% very quickly, indicating high dominance by a few species. The curve for winter shows a rapid initial rise but less steep than summer, indicating moderate dominance. The autumn curve rises more gradually, reflecting higher evenness and lower dominance than summer and winter. The curve for spring is the most gradual, indicating the highest evenness and lowest dominance among the seasons.

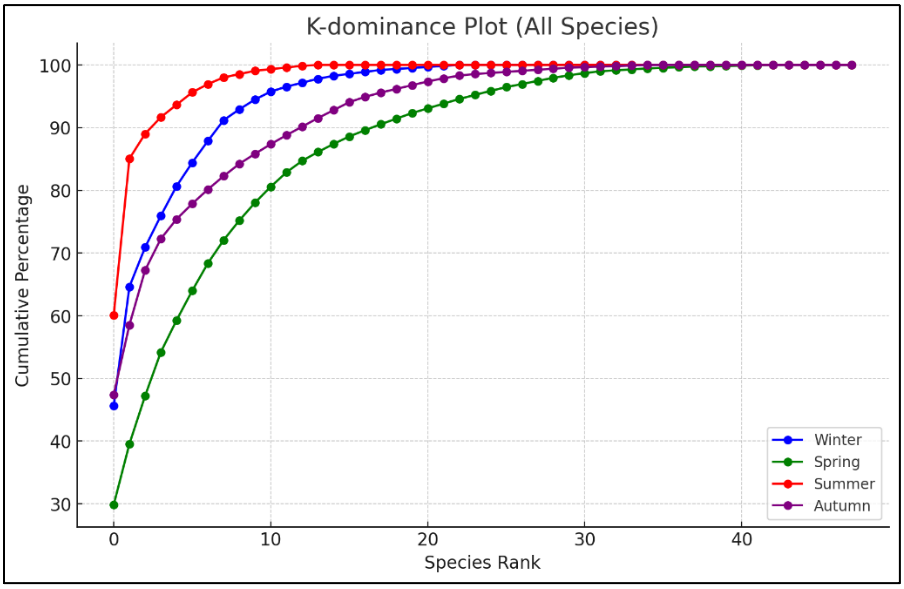

Figure 4.9: K – Dominance plot

4.3.2 Similarity Indices

Cluster analysis adopting Bray-Curtis similarity was performed for comparing the species diversity of different seasons (Fig. 4.10). The dendrogram shows some similarity around 0.69 was observed between Summer and winter among the seasons. Spring and Autumn joined at a similarity level of around 0.71. **Overall,** the two groups (Summer-Winter and Spring-Autumn) cluster together at a lower similarity level of around 0.57, indicating a moderate overall similarity between these two seasonal groups.

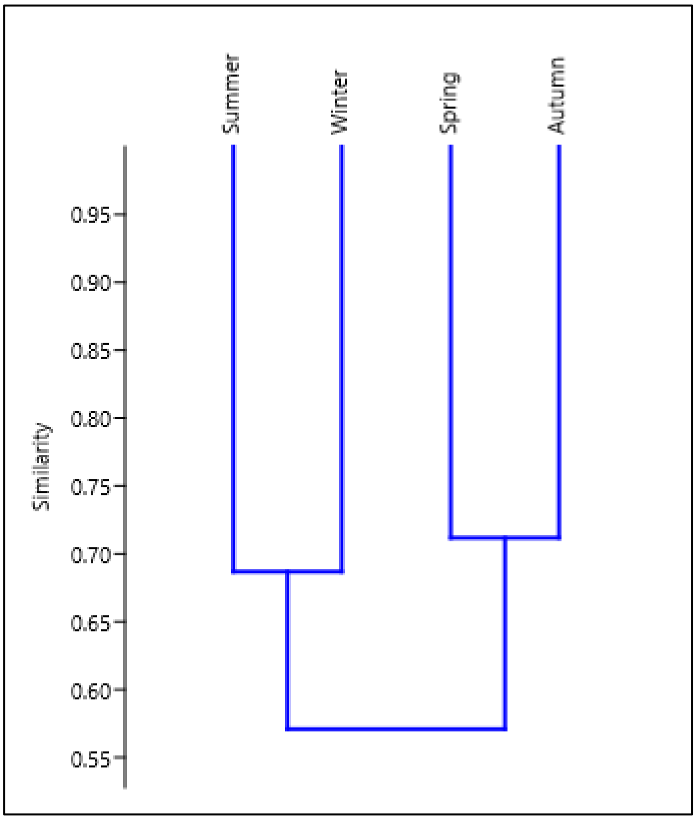

Figure 4.10: Cluster analysis

The NMDS (Non-metric Multi-Dimensional Scaling) plot (Fig. 4.11) provides a visual representation of the similarity in species composition across different seasons. In this plot, each point represents a season and the distances between points reflect the dissimilarities in species composition. The plot shows that Spring and Autumn are positioned close to each other, indicating a high similarity in their species compositions. Summer is somewhat distant from Spring and Autumn but closer to them than to Winter, suggesting moderate similarity. Winter is positioned further away from the other seasons, indicating that its species composition is the most distinct compared to the other seasons.

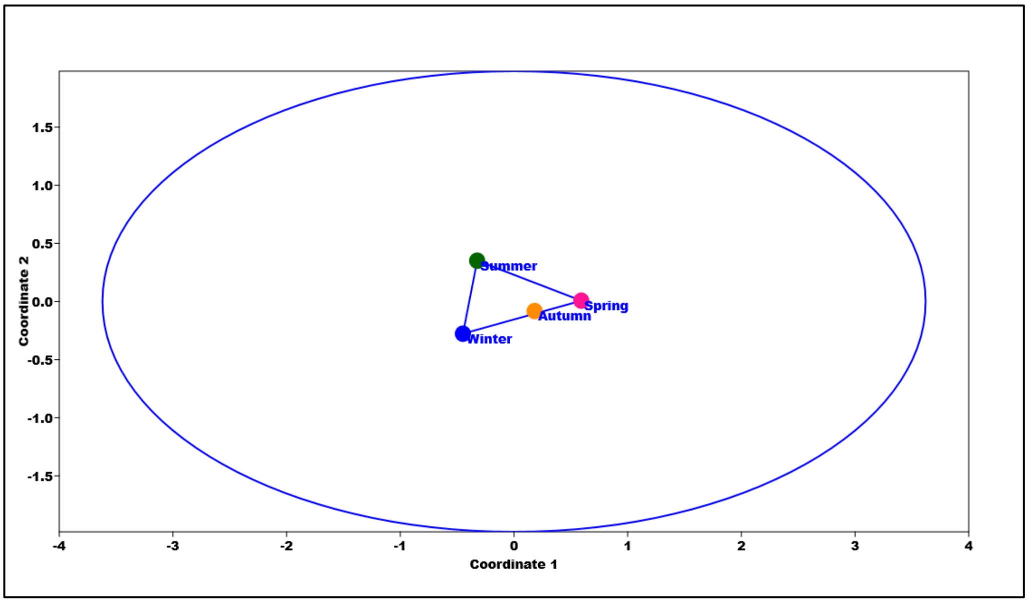

Figure 4.11: Non-metric Multi-Dimensional Scaling

Table 4.1: Season wise catch data of Elasmobranchs from Gujarat coast

Spescie	Winter	Spring	Summer	Autumn
S. laticaudus	290	599	454	559
C. macloti	10	102	2	15
C. melanopterus	0	3	0	2
C. leucas	0	1	0	0
C. falciformis	121	154	189	103
C. sorrah	4	28	30	7
C. limbatus	2	13	0	2
C. amblyrhynchoides	0	1	0	0
G. cuvier	1	26	1	6
R. acutus	32	51	8	16
R. oligolinx	22	57	15	27
G. gangeticus	0	1	0	0
L. macrorhinus	0	3	0	0
S. lewini	8	46	0	18
S. zygaena	0	2	0	0
M. mosis	4	12	0	1
L. omanensis	0	63	0	37
C. arabicum	21	20	4	15
C. griseum	3	13	4	17
I. oxyrinchus	0	95	15	0
A. pelagicus	0	18	0	0
A. superciliosus	0	3	2	0
R. ancylostomus	0	6	0	0
R. laevis	0	2	0	3
G. granulatus	2	10	0	7
G. obtusus	1	0	0	0
R. annandalei	24	140	0	131
R. punctifer	40	195	20	29
T. sinuspersici	11	7	0	19
N. dipterygia	0	0	0	2

P. sephen	5	18	0	2
P. ater	0	10	0	7
B. walga	30	88	10	59
B. imbricata	0	24	0	25
M. gerrardi	1	15	0	0
M. bineeshi	1	1	0	1
M. arabica	0	2	0	23
P. violacea	0	37	2	2
P. bleekeri	0	1	0	0
N. indica	0	19	0	8
H. undulata	1	0	0	1
H. uarnak	0	0	0	1
U. granulatus	0	0	0	1
M. mobular	0	74	0	5
M. tarapacana	0	8	0	0
A. flagellum	0	10	0	10
A. ocellatus	0	15	0	2
G. poecilura	2	15	0	16

4.3.3 Population dynamics and Stock Assessment of *Carcharhinus falciformis* (Bibron, 1839) Silky shark

4.3.3.1 Estimation of Growth Parameters

A Several techniques were employed to estimate the growth parameters. The present study utilized length-based stock assessment methodologies. Analyzed utilizing the FiSATII Computer Program (Gayanilo et al., 1996), the monthly length frequency of *Carcharhinus falciformis* was examined. The FiSATII Software was used to estimate the parameters of von Bertalanffy's growth functions (VBGF), namely the asymptotic length (L∞) and growth coefficient (K), using the ELEFAN-1 routing. A K Scan technique was performed to obtain a dependable estimation of the K value, as described by Pauly and David in 1981.

ELEFAN technique employing FiSATII programme gave an estimate of L_∞ as 326.55 cm TL and K of 0.13/year (Fig. 4.12). Powell and Wetherall plot gives the preliminary estimates of growth parameters L_∞ of 325 cm and Z/K of 3.17 (Fig. 4.13). Shepherd‟s method yielded as L_∞ as 326.55 cm TL and K of 0.13/year. From the growth parameters estimated by all these methods (Table. 4.2), L_∞ as326.55 and K as 0.13/year obtained by ELEFAN method appears to be more reasonable and hence considered for further calculations of population parameters.

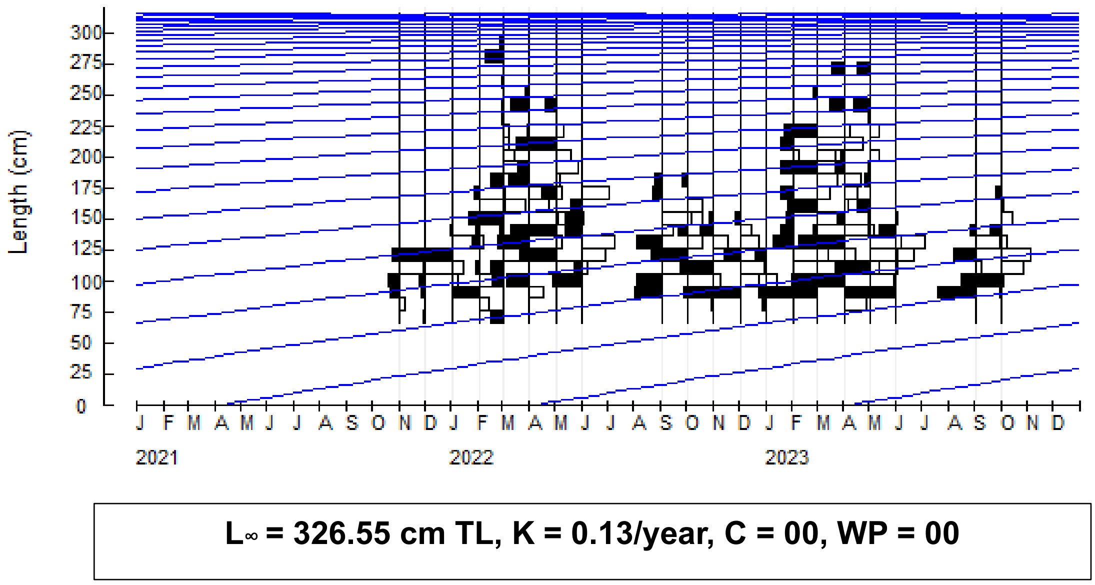

Figure 4.12: Growth curve of *Carcharhinus falciformis* employing ELEFAN

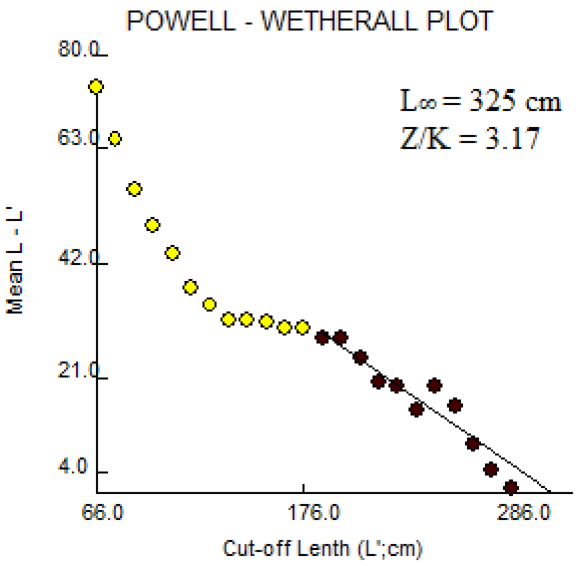

Figure 4.13: Powell and Wetherall plot for estimation of L∞ and Z/K

Table: 4.2 Growth parameter of *Carcharhinus falciformis* estimated by various methods.

Sr. No.	Method employed	L∞ (cm, TL)	K /Year
1	ELEFAN	326.55	0.13
2	Shepherd's method (Shepherd ,1987)	326.55	0.13
3	Powell-Wetherall plot Powell (1979)	325	3.17 Z/K

The Pauly and Munro’s (1984) phi-prime (Φ') value of growth performance index was obtained as phi-prime (Φ') = = (log K+ 2 log L∞) for the present study estimated was 4.142.

4.3.3.2 Mortality Parameters

Total mortality (Z)

The estimated mortality parameters viz. Total mortality (Z), Natural mortality (M), Fishing mortality (F) by length converted catch curve method in *C. falciformis* was 0.45, 0.22 and 0.51 respectively (Fig. 4.14) The fishing mortality (F) was calculated by subtraction of M from Z. The catch curve for the estimation of Z is depicted in (Fig. 4.14) The value of Z estimated by the length converted catch curve was taken for further studies.

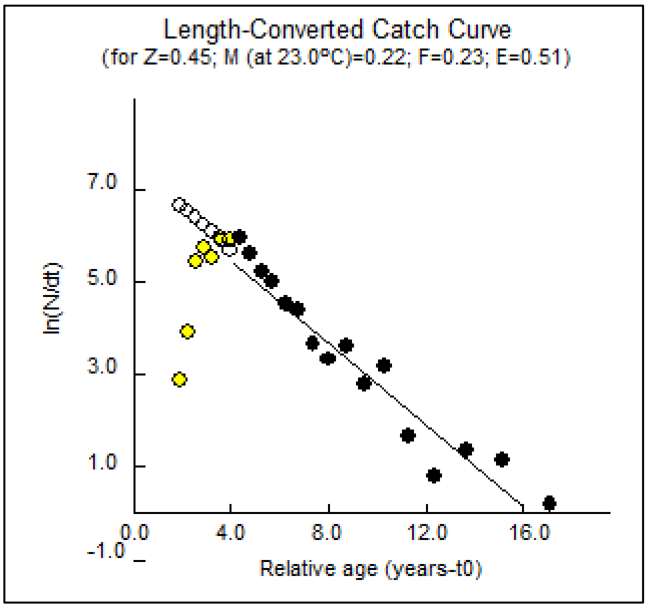

Figure 4.14: Total mortality coefficient (Z) using Length Catch curve method

Natural Mortality(M)

The natural mortality coefficient M was determined using Pauly's empirical formula, yielding a value of 0.22. This value was chosen for subsequent calculations due to its higher reliability and its basis on the link between VBGF parameters and mean habitat temperature.

Fishing mortality (F)

The annual fishing mortality coefficient (F) was estimated by subtracting natural mortality (M) from total mortality coefficient (Z) as 0.23.

Exploitation Rate (E)

With estimated total mortality coefficients (Z) of 0.45 and fishing mortality (F) of 0.23, and the exploitation rate (E) as 0.51.

4.3.3.3 Probability of Capture

From the probability of capture analysis, Length at first capture (L50) value was 101 (Fig. 4.15).

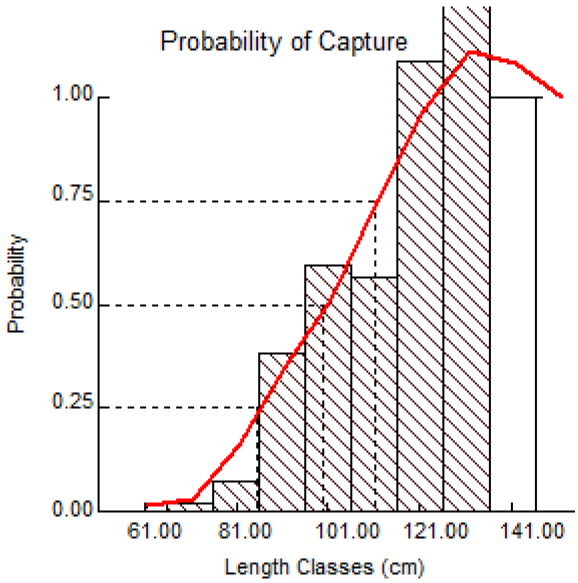

Figure 4.15: Probability of capture for Lc50

4.3.3.4 Recruitment pattern

Results of the analysis of recruitment pattern of *C. falciformis* during the study period is shown in Fig 4.16. Graph shows continuous recruitment throughout the year.

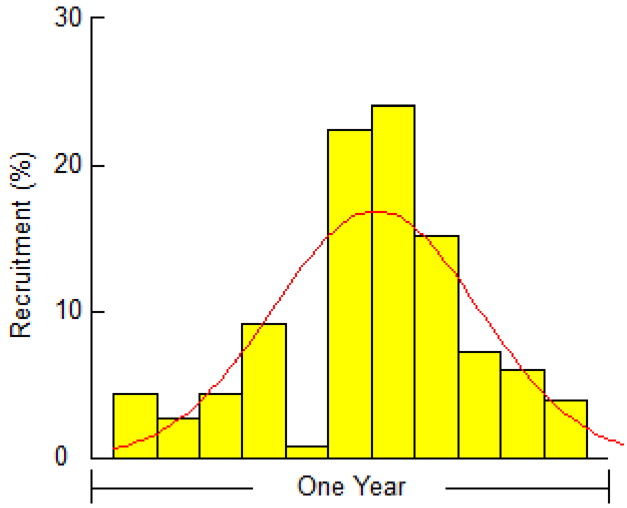

Figure 4.16: Annual recruitment pattern of *C. falciformis* from the Maritime zone of Gujarat.

4.3.3.5 Length structured Virtual Population Analysis (VPA)

The main loss in the stock length group 121-140 cm TL size was due to natural mortality. The highest fishing mortality in the length group of 291-300 cm TL followed by length group 281-290 cm TL. The largest number of fish caught from the length group 71 - 90cm TL followed by 91-110 cm TL (Fig 4.17).

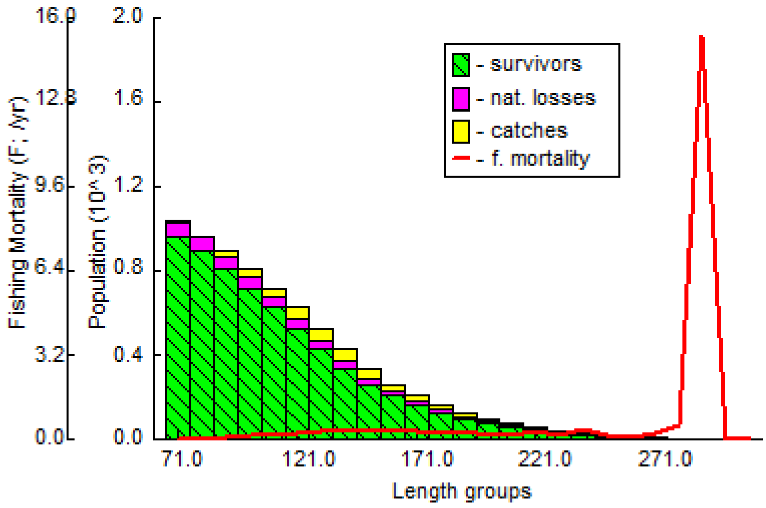

Figure 4.17: Length structured Virtual Population Analysis for *C. falciformis*

4.3.3.6 Relative yield per recruit (Y/R) and Biomass per recruit (B/R)

The Relative yield per recruit (Y'/R) and Biomass per recruit (B/R) were calculated based on the values of LC/L∞ and M/K, which were found to be 0.309 and 1.69 respectively (Fig. 4.18). Figure 4.19 displays the relationship between the plot of relative yield per recruit (Y'/R) and E. The highest Y'/R was achieved at Emax= 0.529. However, once the exploitation rate surpasses this value, the relative yield per recruit declines. E-10 refers to the exploitation level at which the marginal gain in yield per recruit is one-tenth of the marginal increase calculated at a very low value of exploitation. E-50, on the other hand, represents the exploitation level that will lead to a 50% reduction in the unexploited biomass. The maximum value was determined using the yield-per-recruit and biomass-per-recruit model (Fig. 4.19). The anticipated values of E-10 and E-50 were 0.451 and 0.306, respectively.

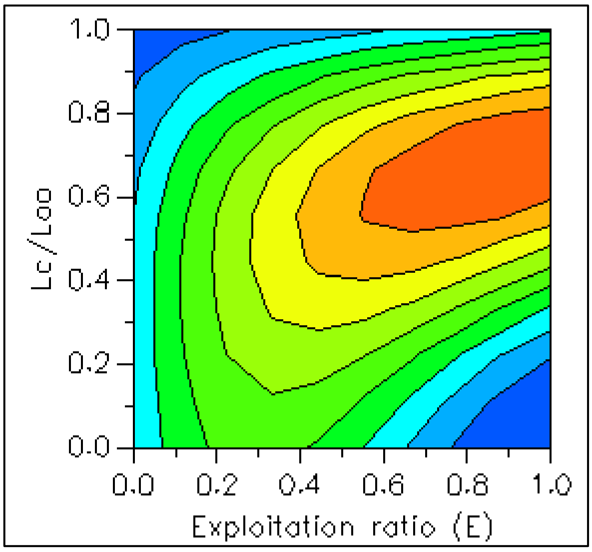

Figure 4.18: Relative yield per recruit isopleth of *C. falciformis* showing the present Y'/R

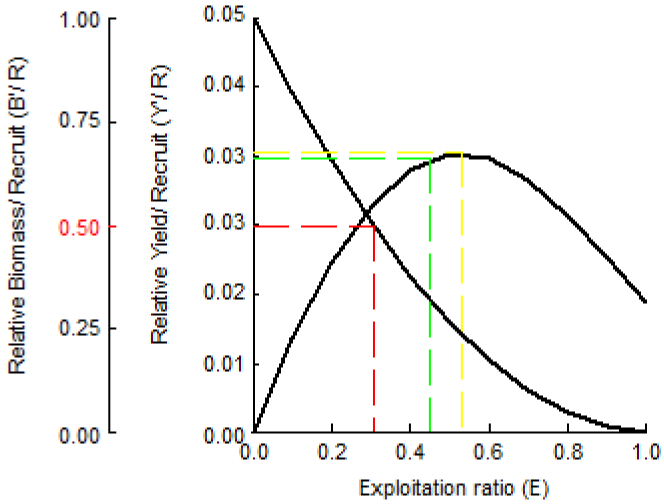

Figure 4.19: Relative yield per recruit Y'/R and biomass per recruit B'/R of *C. falciformis*

4.4 Discussion

A total of 48 species were recorded from the Gujarat maritime zone in the present study. Recently, Johri et al. (2021) recorded 31 species of elasmobranchs from the Gujarat region. Out of the 48 species recorded, only 11 species were found in all four seasons. Understanding the patterns of biodiversity across different seasons is crucial for ecological studies, as it provides insights into the functioning and health of ecosystems.

The findings suggest that biodiversity peaks in the spring, with a notable decline in summer, followed by varying levels in autumn and winter. This seasonal variation in biodiversity is indicative of the dynamic nature of ecological systems, where factors such as temperature fluctuate throughout the year. High biodiversity in spring could be attributed to optimal environmental conditions that support the reproductive cycles and growth of numerous species. Conversely, the lower diversity in summer might result from harsher environmental conditions, such as higher temperatures. Winter, with its moderate diversity, that while conditions are harsher suggests than in spring, they are more tolerable than in summer. Autumn's diversity, being lower than spring but higher than winter and summer, indicates a transitional period with moderate environmental conditions supporting a reasonable variety of species. Ecological stability is often linked to high biodiversity, as diverse ecosystems are typically more resilient to disturbances. The high diversity observed in spring suggests that this season may represent a period of ecological stability, where the ecosystem is robust and capable of supporting a wide range of species.

The richness and evenness of species are critical components of biodiversity. High species richness indicates a variety of species within the ecosystem, while evenness refers to how evenly the individuals are distributed among these species. The patterns observed in this study show that species richness is highest in spring, indicating that this season supports a wide variety of species. This could be due to increased resource availability and suitable environmental conditions that facilitate the survival.

Autumn follows spring in terms of species richness, suggesting that it also provides favourable conditions for a diverse array of species, though not as optimal as in spring. Winter exhibits moderate species richness, reflecting a balance between harsh conditions and available resources that still support a number of species. Summer, with the lowest species richness, indicates that the extreme conditions likely limit the survival and reproduction of many species, resulting in a less diverse ecosystem.

Evenness, on the other hand, provides insights into the dominance and distribution of species within the ecosystem. High evenness implies that no single species dominates the ecosystem, which is often a sign of a healthy and balanced ecosystem. The results suggest that spring also has the highest evenness, further supporting the idea that this season is ecologically favourable. In contrast, lower evenness in summer and autumn indicates that certain species might dominate during these periods, possibly due to competitive advantages in surviving harsher conditions. Winter exhibits moderate evenness, suggesting a more balanced species distribution compared to summer and autumn but less so than in spring.

A similar study conducted by Karuppasamy et al. (2020) in the Wadge Bank, South India, indicates that the post-monsoon season exhibits the highest biodiversity, species richness, and evenness. The pre-monsoon season shows the lowest biodiversity and evenness, while the monsoon and summer seasons have intermediate values, with summer showing slightly higher diversity and richness compared to the monsoon. The possible reason for this variation in results could be the region or different climatic conditions.

The dominance index reveals the prevalence of certain species within the ecosystem. High dominance values indicate that a few species are numerically dominant, which can influence the overall structure and function of the ecosystem. The patterns of dominance observed suggest that certain seasons, particularly summer, are characterized by high dominance. This could be due to the ability of a few species to exploit specific resources or tolerate environmental stressors better than others. High dominance can lead to reduced biodiversity, as dominant species may outcompete others for resources, leading to competitive exclusion. This dynamic is particularly evident in summer, where environmental conditions may Favour certain species, allowing them to proliferate and dominate the ecosystem. In winter and autumn, moderate dominance values suggest that while some species are more prevalent, there is still a reasonable balance among species. Spring, with the lowest dominance, indicates the most balanced ecosystem where no single species overly dominates, allowing for a diverse and stable community.

The SHE analysis (Species richness, Shannon-Wiener diversity, and Evenness) provides a comprehensive overview of the biodiversity patterns across different seasons. This method allows for a detailed examination of how species richness, diversity, and evenness interact and change with varying sample sizes. The steady increase in species richness with more samples indicates that the ecosystem is diverse, and that additional sampling continues to reveal new species. This is particularly evident in spring, where the richness curve rises sharply, reflecting high biodiversity. The stabilization of the Shannon-Wiener diversity index with increasing samples suggests that the diversity levels off after a certain point, indicating a well sampled and understood ecosystem. Evenness remaining consistently low across samples highlights the persistent uneven distribution of species, particularly in less diverse seasons. These insights from the SHE analysis are crucial for understanding the ecological processes that drive biodiversity patterns and for informing conservation strategies.

Individual rarefaction analysis helps to compare species richness across different sample sizes, providing a standardized measure of biodiversity. The results from this analysis indicate that spring has the highest species richness, followed by autumn and winter, with summer having the lowest richness. This standardized approach confirms the overall patterns observed and emphasizes the importance of seasonal variability in shaping biodiversity.

Taxonomic distinctness, which measures the phylogenetic diversity of species, also varies across seasons. High taxonomic distinctness in spring suggests a diverse evolutionary lineage among the species present, indicating a rich and varied ecosystem. Conversely, lower taxonomic distinctness in summer points to a more homogenous species composition, possibly dominated by closely related species that are better adapted to the environmental conditions of that season. Autumn and winter show moderate taxonomic distinctness, reflecting intermediate levels of phylogenetic diversity.

Cluster analysis adopting Bray-Curtis provide insights into the compositional similarity between different seasons. The dendrogram from this analysis shows clear groupings of seasons based on their species compositions, revealing how similar or distinct the seasons are in terms of biodiversity. The grouping of spring and autumn at a higher similarity level suggests that these seasons share more species and have similar ecological conditions. In contrast, the grouping of summer and winter at a lower similarity level indicates distinct species compositions, possibly driven by differing environmental conditions.

Non-metric Multi-Dimensional Scaling (NMDS) further supports these findings by visually representing the dissimilarities in species composition across seasons. Winter, positioned in the negative space on both Axis X and Axis Y, indicates distinct species compositions compared to the other seasons. Spring, with a positive value on Axis X and near-zero on Axis Y, shows unique ecological traits distinct from Winter and somewhat aligns with Autumn, suggesting some shared ecological characteristics between Spring and Autumn. Summer, placed negatively on Axis X and positively on Axis Y, reflects unique ecological conditions, indicating significant differences from Winter, Spring, and Autumn. Autumn, positioned positively on Axis X and slightly negative on Axis Y, suggests ecological attributes that slightly align with Spring but are distinct from Summer and Winter. Overall, the NMDS plot highlights that Spring and Autumn share more similar species compositions, whereas Winter and Summer exhibit significant ecological differences, reflecting the impact of extreme seasonal conditions on species diversity and environmental factors.

Population Dynamics and Stock Assessment of Carcharhinus falciformis

The silky shark, *Carcharhinus falciformis*, is a top predator that migrates extensively and may be found in tropical waters with temperatures above 23°C across the globe. The species is a plentiful pelagic shark that is commonly located in close proximity to the continental and insular shelves, as well as in the open sea. The silky shark is unintentionally caught as by-catch in the Indian Ocean by both small-scale and large-scale fishing operations that use various fishing methods such as purse seine, pelagic longline, and driftnet. The ecological risk study conducted on elasmobranchs affected by longline fisheries in the Indian Ocean determined that the silky shark is classed as a 'high risk species' (Murua et al., 2012). Although silky sharks (Bonfil, 2008) are commercially and ecologically important, there is less knowledge regarding their growth, biology, and ecology. Furthermore, no study has been conducted on the population parameters of silky shark *Carcharhinus falciformis* in Gujarat and India. Gaining a thorough comprehension of the population parameters is crucial for effective fishery management. This study focuses on determining the population parameters and stock assessment of *C. falciformis*.

Table 4.3: Comparison of growth parameters of the von Bertalanffy growth equation of silky sharks reported by various studies

Author	Sampling area	Method	L_∞ (cm)	K/year
Branstetter (1987)	Northern Gulf of Mexico	VCS	291	0.153
Bonfil (1993)	Gulf of Mexico	VCS	311	0.101
Oshitani et al. (2003)	Tropical Pacific Ocean	VCS	287.7	0.148
Joung et al. (2008)	Northwest Pacific	VCS	332	0.084
Sanchez-de Ita et al. (2011)	West coast of Baja California Sur	VCS	240	0.14
Hall et al. (2012)	Off Indonesia	VCS	299.4	0.066
Varghese et al. (2016)	Cochin, Eastern Arabian Sea	LFA	309.8	0.1

The asymptotic length (L_∞) and growth rate (K) values of *C. falciformis* were estimated as L_∞= 326.55 cm and K = 0.13/year. The K value obtained in the present study is aligns with the values of the Growth parameters of *C. falciformis* reported from cochin (Eastern Arabian Sea) by Varghese et al, (2016). Comparing these estimations with the growth parameters in previous reports revealed that the silky sharks in the Gujarat maritime zone grow and reach their maximum length at a faster rate than the stocks in the north-west Pacific and Indonesian waters. However, they grow at a slower pace compared to the silky sharks in the tropical Pacific Ocean and the northern Gulf of Mexico. This information is summarized in the table (4.3) The study conducted by Hall et al. (2012) involved a thorough examination of the age and growth of silky sharks. This was achieved by analyzing growth bands found in parts of the sharks' vertebral centra. They revealed that the rate of growth of this particular species in the eastern Indian Ocean is comparatively slower than the rates observed in the stocks found in the tropical Pacific Ocean and Gulf of Mexico. The variations in growth rates and maximum size of the same species in different geographic regions are primarily ascribed to the variances in latitudes (known as the latitudinal effect) and the disparities in the physical parameters, particularly the water temperatures of the habitats they occupy (Blackburn et al., 1999; Hall et al., 2012).

Branstetter (1987) and Branstetter and Musick (1994) classified VBGF growth coefficient values as slow (0.05-0.1/year), moderately slow (0.1-0.2/year) and fast growing (0.2 0.5/year) species. From the study it can it is confirmed that *C. falciformis* is a moderately slow growing species.

The phi prime (Φ) is a parameter that governs the connection between L∞ and K. The phi prime value estimated in this work, which is 4.142, provides stronger support for the estimation of L∞ and K.

The Total mortality (Z) was estimated by length converted catch curve and is considered as the appropriate method to find out Z, which is 0.45 and has been taken for further analysis. Most of the elasmobranchs have low natural mortality (M) due to low predation and high juvenile survival rate, but the vulnerability to fishing gear will be very high. This study shows the natural mortality coefficient obtained by Pauly's formula was 0.22. The F (0.23) value estimated in this study is higher than M, shows the increasing exploitation of the species. Often M/K ratio, which ranges from 1–2.5 (Beverton and Holt, 1959) in most of fish, becomes a method of testing the accuracy of estimation of M. In the present study the M/K ratio (1.69) of the species fall in that range thus providing the consistency of the same on the M/K ratio. The exploitation rate (E) value estimated as 0.51. Gulland and Holt (1959) suggested that the optimum value of E is 0.5 above which the stock under study is overexploited. As the estimated

E is slightly above the optimum value of E (0.5) so the stock can be considered as over-exploited.

In the present investigation no data could be collected during in the July and August month of 2022 and 2023 because the onset of monsoon and seasonal fishing banned implemented by Government of Gujarat. The length at first capture (Lc) in the present study is estimated to be 101 cm TL. Bonfil (2008) reported that Lengths at maturity of females *C. falciformis* are in the range of 180–260 cm total length, whereas the males attain maturity at the Total length of 180–240 cm. However, the length at first capture in the present study (101 cm) is indicating there is tremendous pressure on the immature *C. falciformis* stock in the Gujarat maritime zone. Decreasing the fishing pressure will give the fish a chance to mature before being caught in large numbers.

This study revealed that the recruitment pattern of *C. falciformis* shows continuous recruitment throughout the year, with a two peak around June and July month. The percent recruitment varied from 0.8% to 23.97%. The highest (23.97%) and lowest (0.8%) percent recruitment was observed in the months of July and May respectively.

VPA revealed that F increases to maximum at 241-250cm TL, after this point it decreases at 261-270 cm TL and abruptly increases at 291-300 cm TL. The reason for this sudden increase in F possibly due to larger sharks is coming as bycatch.

The knife-edge method yielded an Emax value of 0.529 in the current study. The fundamental premise of knife-edge selection is that fish below the length at which they are initially caught will not be kept by the net. The E value, determined by the ratio of F to Z, is 0.51.

The general rule of thumb is that when Z/K is greater than 1, it suggests that the fish population is primarily affected by mortality. Conversely, when Z/K is less than 1, it indicates that the population is primarily influenced by growth. However, the Z/K value of 3.46 in the present study indicates that the population is predominantly influenced by mortality. Most likely, in Indian seas, the majority of species experience high mortality rates. According to Pauly and Soriano (1986) in the isopleth diagram where Lc /L_∞, E and M/K ratio are compared, the stock are classified into four quadrants, in the present case with L c/L_∞ of 0.309 and E of 0.51 it belongs to quadrant

C which implies that large specimen can be caught at higher efforts and fishery is stabilized and developed. The species presently investigated fits under the same category and probably a slight reduction of effort may give sustained fishery.

The Relative yield per recruit (Y/R) and Biomass per recruit (B/R) were determined as a function of LC/L∞ and M/K. The fishes with low K values are characteristic with low natural mortality, K value in the present study is 0.13/year and the corresponding M value is 0.22. Therefore, the M/K ratio of *C. falciformis* is found to be 1.69. The M/K ratio is found to be constant among the closely related species and the M/K ratio in fishes generally falls within the limit of 1.5-2.5 (Beverton and Holt, 1959). The exploitation rate (E) is 0.51. When E is more than 0.5 for the stocks, are supposed to be over exploited (Gulland, 1971). The results of the present study ascertain the need for monitoring the fishing effort for *C. falciformis* along the maritime zone of Guajart State, India.