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FISHERIES MANAGEMENT FOR FOOD SECURITY IN THE MALDIVES

Purpose. *The goal of the study was to assess trends in providing food security with a special emphasis on efficiency of the local fisheries and offer evidence-based improvements, which can improve resource management and protect disadvantaged population in the Maldives from nutrition insecurity aggravated by strong import dependency.*

Methodology / approach. *The methodological basis of this study was a set of modern qualitative economic and quantitative mathematical methods including factor analyses, econometric and optimisation modelling. This approach ensured holistic research and reasonable recommendations on providing food security and maintaining efficient fisheries management compared to international experience and intrinsic aspects that determine a fish catch and consumption in the Maldives.*

Results. *The conclusions of the paper relate to the further development of fisheries to combat the identified negative trends in domestic fish consumption and an unstable fish catch by atoll in the Maldives. The conducted factor analysis detected relationships between a fish catch, fishing trips, engaged vessels, fish species, and fishing methods. The study findings proved the optimal locations where it is advisable to establish additional fish storages and ice plants taking into account indicators of a poverty rate, a share of children, and a population density. The research conclusions allow the authors to state that the outlined scientific proposals can essentially improve food security in the Maldives, which is threatened by land shortage and overpopulation.*

Originality / scientific novelty. *The scientific novelty of the work is in presenting a clarified picture of challenges that Maldivian fishermen face nowadays. The scientific novelty lies in the identification of weaknesses in fisheries management and the proposals of areas of potential growth that are crucial for ensuring food security not only on poor islands but for the whole country.*

Practical value / implications. *The main practical value of the research results is the development of recommendations for increasing fish catch and organising post-harvest processing, which are vital for the Maldivian fishery, as it is the country's main export sector. In addition, the study contributes to food security in the Maldives through proposed interventions aimed at supporting the most disadvantaged populations in the scattered atolls.*

Key words: *food security, a fish catch, trends in production and consumption, resource management, disadvantaged population, optimisation model for fish storages.*

1. INTRODUCTION

Agriculture is playing a vital role in providing food and nutrient security in a changing, increasingly interconnected globalised world where resources are limited and the population continues to grow fast. The challenge lies in meeting the raising demand for food while ensuring sustainable use of finite resources, adapting to climate change, and addressing inequalities in access to nutritious food. Achieving food and nutrient security requires coordinated efforts to improve agricultural productivity, promote sustainable practices, address trade barriers, and enhance resilience to shocks caused by natural disasters, pandemics, and wars [1].

It is essential not only for preventing hunger and malnutrition but also for promoting health, economic development, and social stability in a rapidly evolving world [1]. International teams of scientists from all over the world claim that the ongoing Russia-Ukraine war has been exacerbating food insecurity, extending beyond the immediate battlefield and revealing breaches in global food security systems [2; 3; 4]. Similarly, the COVID-19 pandemic has significantly disrupted food and nutrient security globally, affecting agricultural pricing, supply chains, and consumer behaviour. It detected short-term bottlenecks in supply chains such as low stocks and transportation restrictions [5]. These cases have highlighted the major importance of food security as a fundamental part of national resilience, development and prosperity.

Globalisation has profoundly influenced food security in South Asia. Historically most people from coastal regions in South Asia consumed freshly grown vegetables and fruits as well as a fresh fish caught from seas as their main diet. Rapidly growing population, urbanisation and increasing resource have led to higher prices for local food, pushing people to Western refined and energy-dense foods and nourishment preferences. While globalisation has brought economic opportunities to South Asia, it has also exacerbated disparities in access to nutritious foods relying heavily on imports. As a result, South Asian countries are now struggling with the double burden of malnutrition and obesity, which cause nutrition-related non-communicable diseases [6].

The Maldives is an overpopulated region of South Asia with limited natural resources. The Maldives consists of 20 administrative atolls including North Thiladhunmathi (HA), South Thiladhunmathi (HDh), North Miladhunmadulu (Sh), South Miladhunmadulu (N), North Maalhosmadulu (R), South Maalhosmadulu (B), Faadhippolhu (Lh), Male' Atoll (K), North Ari Atoll (AA), South Ari Atoll (ADh), Felidhu Atoll (V), Mulakatholhu (M), North Nilandhe Atoll (F), South Nilandhe Atoll (Dh), Kolhumadulu (Th), Hadhdhunmathi (L), North Huvadhu Atoll (GA), South Huvadhu Atoll (GDh), Fuvahmulah (Gn) and Addu Atoll (S) [7]. The main challenges faced by the Maldives in ensuring food security are high population density, which is among the top 10 countries in the world, as well as land and freshwater scarcity.

Hence, the national agriculture presented by crop production cannot meet the domestic demand for nourished food [8]. That is why from the beginning the national fisheries sector has contributed as a way of living for Maldivian people who relied on fish as a primary source of animal protein, omega-3 fatty acids, vitamins, and minerals. Beyond cultural significance, fish accessibility and affordability make it a vital component of everyday meals for the majority of Maldivians. Similarly, on a global scale, the fisheries sector plays a critical role in food and nutrition security serving as a prevalent food source for local low-income populations and acting as a safety net during economic and climatic crises [9].

The importance and scale of the fisheries sector in combating world hunger, addressing malnutrition, and supporting the livelihoods of millions in rural coastal areas have attracted considerable attention from the global community. The international community recognises the importance of sustainable fisheries management for the conservation and sustainable use of ocean resources. This commitment is reflected in SDG 14 of the United Nations 2030 Agenda for Sustainable Development. Effective fisheries management is vital for maintaining fish stock and optimizing their productivity [10].

Given the significance of the fisheries sector in food and nutrient security, as well as the economic viability of the nation, the Maldives Blue Economy document places great emphasis on sustaining the fisheries sector. This includes implementing sustainable practices in fisheries management to ensure the long-term health of marine resources. The document further emphasises robust governance and regulation of fishing activities, preventing overfishing and unregulated fishing practices, strengthening market access, and improving fisheries sector infrastructure to enhance food and nutrient security. However, despite all of the above, the daily protein intake in the Maldives has dropped drastically by almost 40 % since 2011 [11]. It proves that the research topic linking food security and improvements of fisheries management is timely and relevant.

The purpose of the article was to explore the Maldivian food security dependent on productivity of fisheries and clarify urgent management improvements which can enhance their efficiency.

2. LITERATURE REVIEW

The Maldives is the second country in the world by fish consumption with over 83.1 kg/capita/year from local fishermen. The other leaders are nations mostly from islands or located in the Asia-Pacific region, in particular Iceland, Kiribati, two special regions of China – Macau and Hong Kong, Portugal, the Seychelles, South Korea, and Malaysia where the total fish and seafood consumption accounts for 90.6, 73.3, 73.2, 65.8, 60, 56.8, 55.3, 54.7 kg/capita/year, respectively, including freshwater fish which is unavailable in the Maldives [12]. Ukrainian results in fish production are much more modest, especially after Russian occupation of Crimea in 2014. At that time, due to a sharp decrease in the marine fish catch, total fish production dropped by 2.8 times from 216 thousand tons to 81 thousand tons. At the same time, fish consumption shrank down to 8.6 kg/capita/year. This indicator had raised to 13.2 kg/capita/year by 2021 [13]. However, after Russian invasion in Ukraine in 2022, local fishermen lost 46% of their freshwater fish resources, in particular after undermining the Kahovka HPP dam by Russian military in 2023. This unprecedented ecocide caused reduction of Ukrainian fish production down to 22.5 thousand tons [14].

According to A. Jaleel & H. D. Smith the fishing industry in the Maldives has been undergoing significant changes since the 1970s. Traditional methods gave way to mechanisation and modern technologies, with larger vessels and sonars replacing manual detection techniques. Looking at the fisheries sector of the Maldives from the management and governance side the study showed that there are several major challenges faced by the fishermen and by the sector as a whole which hamper its growth and development. Indeed, geographical and seasonal fluctuations of monsoon centered on the Indian Ocean reduce the continuity of the fishing activities. This narrows down the chances of Maldivian fishermen accessing the international tuna market as the Maldives cannot guarantee a steady supply throughout the year [15].

Iceland is a European nation well known for managing its large fishing industry in a sustainable and profitable way. Similar to the Maldives, Icelandic fisheries sector acts as a primary economic activity providing income, employment, and export revenue. The nation has adopted diverse management strategies such as Individual Transferable Quotas (ITQs) with exempted limitations for the rural small-scale fishing communities safeguarding their way of livelihood [16]. The country also implemented Total Allowable Catches (TACs) based on scientific guidance and restrictions on foreign ownership of ITQs, further protecting their marine biodiversity and ecosystem through innovative practices and collaboration with stakeholders. These initiatives can be a guiding vector for the Maldivian fisheries sector which balances the stability of the whole nation [16].

Kiribati, like the Maldives, heavily depends on its fisheries sector for economic development and revenue generation, given its vast ocean territory and abundant marine resources. Both countries have experienced significant growth in tuna fishing over the past few decades, contributing substantially to their respective economies. Kiribati's establishment of marine protected areas, such as the Phoenix Islands Protected Area (PIPA), mirrors the Maldives' efforts in marine conservation and sustainable fisheries management. However, Kiribati faces challenges in balancing sustainable fishing practices with revenue generation, as evidenced by the recent decision to reopen PIPA to commercial fishing [17]. Kiribati IMF Staff Country Reports of 2023 argued that management measures taken by Kiribati include a multifaceted approach to fisheries management aimed at ensuring the sustainability of its marine resources. This strategy involves regional cooperation through agreements like the Nauru Agreement, which coordinates tuna purse seine fisheries management among Pacific Island nations. Additionally, Kiribati uses the Vessel Day Scheme to regulate fishing efforts, preventing overexploitation of fish stocks. Kiribati serves as an example of countries striving to manage their fisheries resources sustainably while leveraging their marine assets for economic development [17].

W. A. Karp et al. argued that Norwegian fisheries management is another example where the national fisheries sector operates through a comprehensive regulatory framework known as the "Discard Ban Package" (DBP), which controls fishing licenses, quotas, and exploitation patterns. The DBP consists of various measures aimed at minimising unwanted catch, including a discard ban, gear selectivity techniques, closed areas, monitoring, and control measures [18].

Similar to developed countries many developing nations highly depend on fisheries sector as their source of protein in their daily meals. South-East Asian countries like Thailand and Vietnam addressed discard problems by developing alternative industries such as fish meal for animal feed and surimi for human consumption. These initiatives not only reduced discard levels but also created value-added products contributing to economic growth [19].

Similarly, in India as it was noted by W. A. Karp et al. regulations were implemented to prevent substantial surplus catch waste, although enforcement has been challenging. Nevertheless, the region's focus on utilising most catches for protein-rich foods has kept discard levels relatively low over the past three decades. Overall, these management strategies in South-East Asia benefit the fisheries sector by minimising wastage, supporting alternative industries, and ensuring the efficient utilisation of fish resources to meet the demand for protein-rich foods [18].

Enhancing the capacity to gather both fishery dependent (e.g. catch and effort data) and independent data (e.g. gear selectivity) is vital for improving fisheries governance, yet this information is often restricted in developing nations. In this context B. M. Drakeford et al. proposed management measures such as Fisheries Transparency Initiative (FTI) and data management as promising ways to strengthen and improve the sustainability of the Seychelles fisheries sector [20]. This research explored vulnerability of fishery-based livelihoods to climate variability in the Seychelles and underscored the significance of using locally tailored indicators to assess the climatic impact on fishing communities, enabling targeted interventions. Investments in infrastructure, like processing plants and landing sites, would enhance resilience by generating income opportunities and improving market access. Challenges such as increased travel distances for fishers highlighted the need for comprehensive management strategies. Further research was recommended in two areas: assessing the impacts of subsidies and sustainable fisheries management and adopting a value-chain approach to understand small-scale fishers' vulnerability. Certainly, this approach can also benefit the Maldives, another island nation heavily reliant on fisheries [21].

Malaysia, a significant global fish producer, faces a fish trade deficit despite its abundant water bodies, suggesting potential competitiveness challenges in the global market. Research on Malaysian fisheries exports used a modified constant market share (CMS) analysis to assess the export competitiveness of Malaysian fisheries sector, which was the strongest for frozen fish and the weakest in case of crustaceans. This study revealed an untapped export potential in certain product categories, informing policymakers and traders about advanced strategic planning to enhance Malaysian fisheries position in the global market [22].

Indonesian small-scale fisheries (SSFs), much like the Maldivian small-scale fishermen employ a large workforce and provide 50 % of the national catch. However, they face challenges like increasing demand and declining stocks. I. Jaya et al. suggested principles for effective fisheries management, emphasising understanding the broader context, addressing constraints, and ending subsidies. Implementing these principles can help create sustainable fisheries, supporting coastal livelihoods and conserving marine resources [23].

Sri Lanka's pole-and-line and hand line tuna fishing industry has experienced a sharp decline in the fisheries sector over the past three decades. According to

R. Maldeniya et al., the fisheries sector in Sri Lanka needs effective sustainable management practices such as upgrading vessels, introducing Fish Aggregating Devices (FADs), improving the forecasting of tuna schools, and developing efficient methods for harvesting live bait [24]. Qualitative research done on expanding the export market of the fisheries shows the importance of Halal certification for fisheries products as a management strategy and underscores the need to address the identified obstacles. A. Muneeza & Z. Mustapha stated that comprehending these challenges, the Maldives could work towards establishing robust and standardised Halal certification criteria, thereby fostering the growth of its Halal industry, including the fisheries sector [25].

Overall, effective management strategies implemented by both developed and developing nations present model management measures that can be implemented to improve and strengthen the fisheries sector of the Maldives that shares similar characteristics. However, fisheries in the Maldives have a special economic and social niche as fish is the primary source of animal protein there. Sustainable fisheries are a vital pillar that bolsters the national food security not to mention that the Maldivian agricultural sector is limited to crop production and is totally unable to meet increasing food security challenges. Any natural disasters (such as tsunamis, high waves, heavy rain) and trade restrictions (like the COVID-19 shutdown) have a catastrophic impact on the whole country, as over 50 % of the national food demand is covered through imports and vulnerable people from disadvantaged atolls may be doomed to starvation. Therefore, national sources of food are invaluable and it is imperative to support, develop, and sustain the fisheries sector to ensure food security in the Maldives.

The research questions addressed in the paper dealt with: (i) revealing peculiarities of the national food security component linked to fisheries; (ii) specifying managerial improvements to support fisheries in the Maldives.

3. METHODOLOGY

This study based on the panel data on fisheries in the Maldives largely provided by the Maldives Bureau of Statistics to cover the research time framework starting from 2011 to 2023 (if available). In order to perform this research, the study exploited an integrated approach that combines both quantitative and qualitative methods of analysis to maintain a holistic investigation of how to mitigate food insecurity and facilitate fisheries development.

Qualitative methods used to carry out this research-based systematisation, synthesis, comparison, and analogy to examine contemporary scientific results adjacent to the paper topic, whereas deduction and generalisation were involved in making assumptions and conclusions.

Quantitative methods used in the study were based on statistical analysis and optimisation methods intended for comparing, visualising, and modelling the research data [26; 27]. Firstly, regarding the ongoing trends in the Maldivian food security, the study used a simple linear regression:

$$Y = A_1 \cdot X + A_0, \quad (1)$$

which coefficients A_1 reflected dynamics of the investigated indicators. The significance of the obtained econometric models was checked by means of R square (R^2) and confirmed by running Fisher's criterion, i.e.:

$$R^2 : (1 - R^2) \cdot (df_2 : df_1) = F_{calc} > F_{crit}(\alpha, df_1, df_2), \quad (2)$$

where $F_{crit}(\alpha, df_1, df_2)$ is a critical value with a significance level of α and degrees of freedom $df_1=1$ and $df_2 = N-2$ if a count of values in the sample equals N.

To assess a fish catch by atoll the study used basic statistics. As a result, a sample mean (C_{mean}) and a coefficient of variation (CV) were visualised in combo charts to compare scales and relative stability of a fish catch by atoll within the given time frame, where:

$$CV = C_{st.dev.} : C_{mean} \cdot 100\ \%, \quad (3)$$

where $C_{st.dev}$ denotes the sample standard deviation.

Concerning resource management in fisheries, it was advisable to apply the Spearman rank correlation test to find out connections between fishing trips, a fish catch per unit effort, a number of trips per vessel, and their quantities by atoll. Mathematically it looked like calculating the Spearman rank correlation $R_{Spearman}$ between ranked samples of $B1$ and $B2$ given by the formula as follows:

$$R_{Spearman} = 1 - 6 \cdot \Sigma_{i=1...N}(B1_i - B2_i)^2 : (N \cdot (N^2 - 1)), \quad (4)$$

and then comparing the test statistic (supposed negative) to a critical value (supposed negative) of the standard normal distribution $N(0,1)$ with a given significance level of α, namely:

$$(6 \cdot \Sigma_{i=1...N}(B1_i - B2_i)^2 - N \cdot (N^2 - 1)) : (N \cdot (N+1) \cdot (N-1)^{0.5}) = S_{calc} < N(0,1)_{critical}(\alpha). \quad (5)$$

This inequality enabled the authors to confirm similar trends observed in the compared indicators.

Dynamics of a monthly fish catch by fish species was assisted by box and whisker plots which showed average values, upper and lower extremes, outliers, and middle quartiles of the analysed samples.

In order to find the best locations of fish storages and ice plants the research resulted in a binary linear optimisation model formulated as follows. X_m denoted binary variables associated with potential locations of fish storages and ice plants on M selected islands, $m=1...M$. To distinguish more disadvantaged places to be supported, the authors introduced weight coefficients W_m, $m=1...M$. D_{km} denoted binary parameters meant to mark that island k and m are situated at a feasible distance regarding fish post-harvest transportation, $k=1...M$, $m=1...M$.

The model constraints about the demand to offer each island at least one additional fish storage and an ice plant located on this island or on the neighbouring ones were described by the formulas:

$$\Sigma_{m=1...M} D_{km} \cdot X_m \geq 1,\ k=1...M. \quad (6)$$

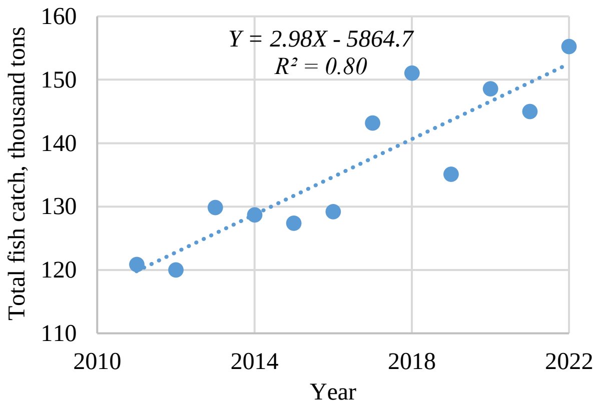
The model objective function calculated the weighed total implying the minimal number of additional fish storages and ice plants to support food security on the most disadvantaged atolls:

$$\sum_{m=1\ldots M} W_m \cdot X_m \rightarrow min. \quad (7)$$

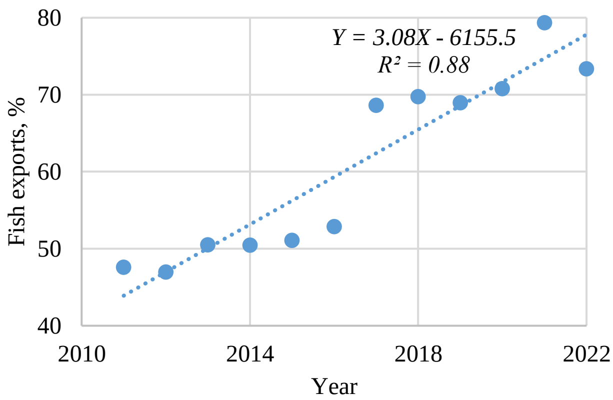
All of the above formulas and models were calculated using MS Excel and Google Sheets.

4. RESULTS

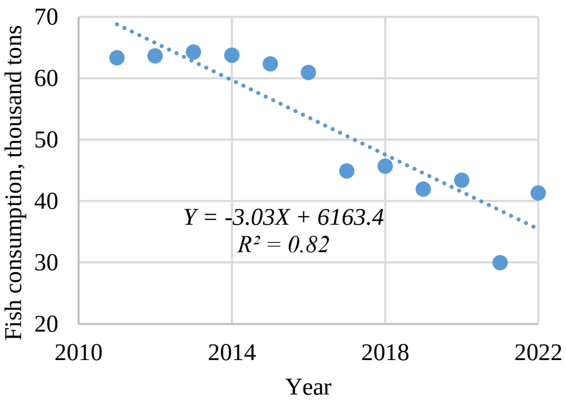
In compliance with the research goal and methodology, the study has evaluated the state of a fisheries component in the Maldivian food security within the time frame of 2011–2022, so that $N = 12$. The research data was retrieved from official sources [7; 11] encompassing indicators of an annual fish production, exports, and local consumption as well as a daily animal protein intake from fish. The initial data and obtained simple linear regressions are illustrated in Figure 1.



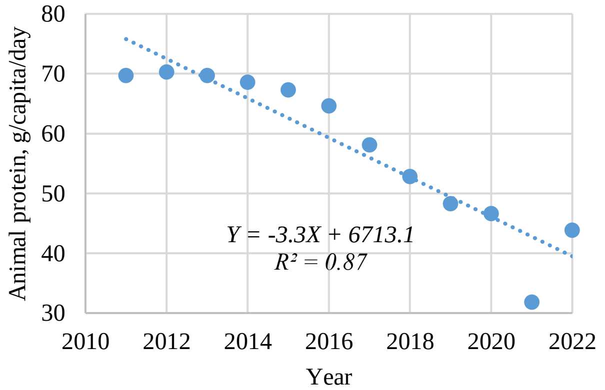
a) Dynamics of the total fish catch



b) Dynamics of fish exports



c) Dynamics of fish consumption



d) Dynamics of animal protein intake

Figure 1. Dynamics of food security by fish in the Maldives

Source: composed by the authors based on data from [7; 11].

Regression formulas (1) and calculations on their significance are presented in Table 1. In all cases R square identified strong linear changes of the analysed indicators over time. The study considered a conventional significance level of $\alpha = 0.05$. Therefore, according to Fisher's criteria (2) with $F_{crit}(0.05, 1, 10) = 4.96$, are more than 95 % confident that the calculated regressions provide adequate characteristics of the trends under study, which are as follows.

Table 1

Trends in food security by fish in the Maldives

Indicator	Regression	R^2	F_{calc}
The total fish catch, thousand tons	Y = 2.98X – 5864.7	0.80	39.83
Fish exports, %	Y = 3.08X – 6155.5	0.88	72.18
Fish consumption, thousand tons	Y = –3.03X + 6163.4	0.82	45.10
Animal protein, g/capita/day	Y = –3.3X + 6713.1	0.86	63.40

Source: calculated by the authors based on data from [7; 11].

Calculations on assessment of production management via fisheries efficiency by atoll are visualised in Figure 2 that enables the authors to compare average fish catch shares and their variations in 2018–2022.

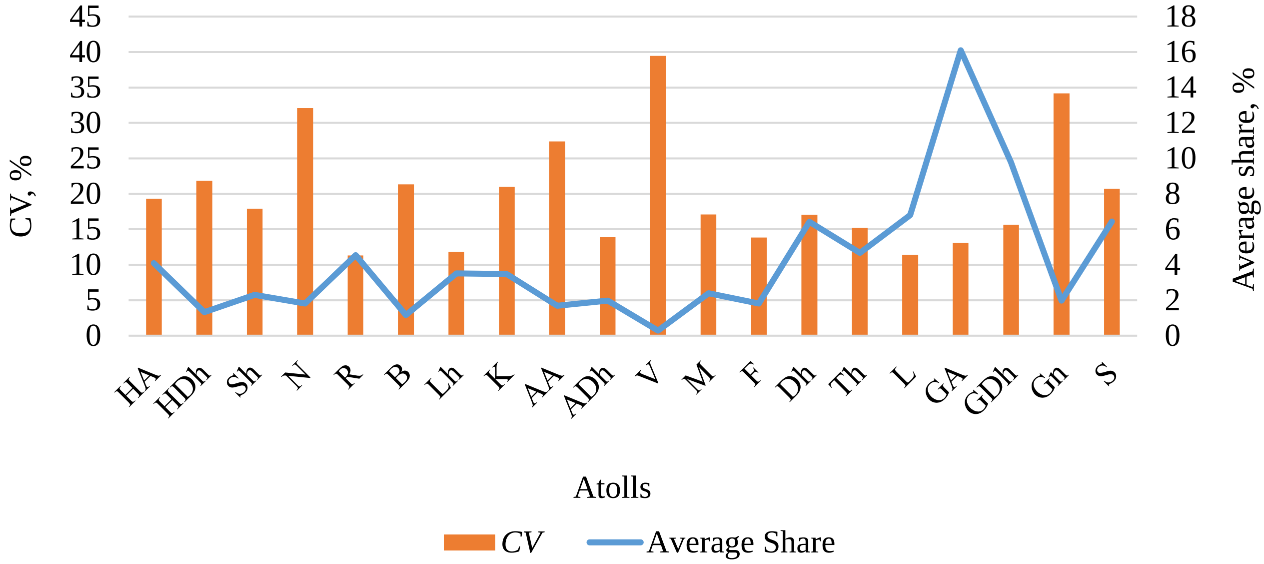


Figure 2. A fish catch by atoll in the Maldives in 2018–2022

Source: composed by the authors based on data from [7].

Mathematical analysis of resource management in atoll fisheries in 2022 was carried out according to the Spearman's rank correlation test (formulas (4) and (5)) and involved 5 indicators such as:

1) a fish catch,
2) a number of fishing trips,
3) a fish catch per fishing trip,
4) a number of vessels,
5) a number of trips per vessel.

The results of the performed calculations were comprised in Table 2. With a conventional significance level of α = 0.05 and a critical value of $N(0,1)_{critical}(\alpha)$=–1.64, the authors are over 95 % sure that there are a very tight relationship between a fish catch and a number of fishing trips whereas the other identified relationships are strong.

Another issue worth investigating is the uneven monthly fish catch, which threatens food security and affects the utilisation of fish storage facilities and ice generators. The prime fish species caught in the Maldives are skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*) with a cumulative share in the total fish catch of more than 98 % over the last 5 years.

Table 2

Tests on resource management in fisheries in the Maldives in 2022

Relationship	$R_{Spearman}$	S_{calc}
1 & 2	0.93	–3.94
1 & 3	0.74	–3.09
1 & 5	0.85	–2.60
2 & 4	0.77	–3.67
2 & 5	0.79	–3.17

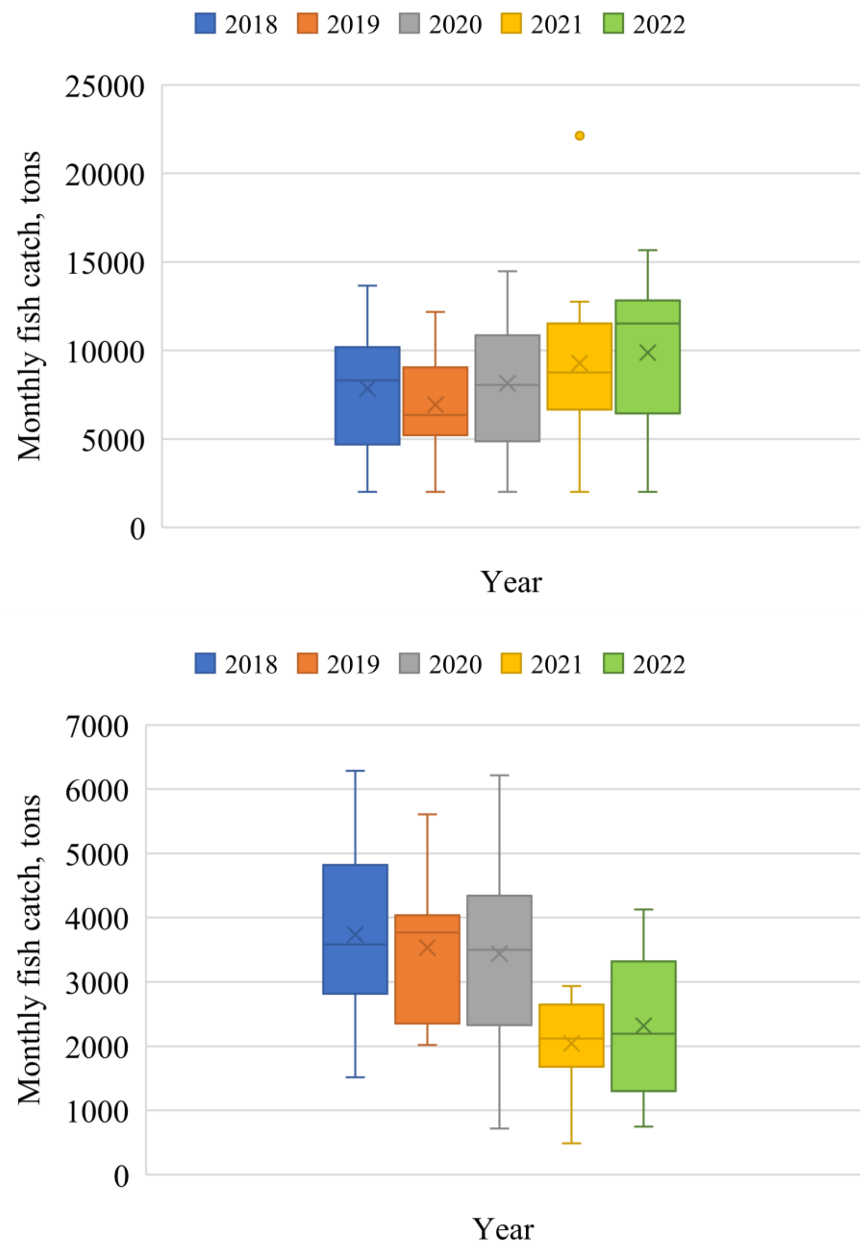
Source: calculated by the authors based on data from [7].

Skipjack is black, dark purplish to purple blue epipelagic and oceanic tuna locally known as *Kalhubilamas* with a varying size from 70 cm to maximum 1.1 m. Skipjack fishing predominantly takes place in deep-sea environments. Yellowfin tuna locally referred to *Reendhoo uraha kanneli* is metallic steel blue on back to silvery below epipelagic and oceanic fish which grows up to maximum 2 m, feeds near the surface and, being a predator, reacts to moving baits. The study has analysed dynamics of skipjack and yellowfin tuna catches from 2018 to 2022 (the last available year in official statistics). To address this task the authors developed box and whisker charts introduced in Figure 3.

One major concern raised by the fishermen since the beginning include not being able to sell their catch due to a long time necessary to land or outreach trading centres or fish storage facilities which leads to deterioration of the fish quality as well as fishermen have to waste an ample amount of time that could be spent on fishing. Besides, the expansion of tourism activities such as diving and sea excursions have pushed the local fishermen to tourism industry as a reliable mean of earning income. Those who are still involved in fishing struggle to purchase ice that is a pre-requirement for handling skipjack and yellowfin tuna catch. To ease the burden on fishermen, the authors found the best locations for additional fish storages and ice plants.

The potential locations were chosen by three indicators: a poverty rate, a share of children, and a population density, whose values were retrieved from [7; 28]. The selected islands were those with higher levels of a poverty rate and a share of children compared to the average ones in the Maldives.

The research indicates that 10 out of 20 administrative atolls in the Maldives experience significantly higher levels of poverty compared to the national average. This suggests that the current national food security basket may not be adequately addressing the specific needs of these poorer regions such as HA, HDh, R, K, AA, F, Th, L, GA, GDh atolls. The geographical dispersion of the islands and the concentration of secondary and tertiary economic activities in the capital city Male' deprive rural island communities of participation in these sectors. Consequently, islands lacking access to tourism-related job opportunities rely heavily on primary economic activities such as fishing and agriculture. These economic activities have traditionally ensured the stability of these rural communities. However, changing climatic conditions, environmental degradation due to a lack of sustainable practices, and the migration of the young population to areas with higher income opportunities have disrupted food production and nutrient security. For example, atolls like HDh, N, B, AA, and V have been severely affected by climatic changes and natural disasters, impacting fish abundance and distribution. The lack of storage and processing facilities and limited capacity to convert raw catch into value-added products further exacerbate economic instability.



a) Skipjack

b) Yellowfin tuna

Figure 3. Monthly dynamics of a fish catch in the Maldives in 2018–2022

Source: composed by the authors based on data from [7].

Additionally, small island communities with high population densities face limited access to arable land for farming. Even where land is available, farmers struggle due to financial constraints, environmental degradation, and a lack of knowledge and skills. These islands lack economic diversification beyond fishing and tourism, leaving them with no alternative sources of income and relying solely on these activities for food and nutrient security. Higher poverty levels often correlate with increased food insecurity, meaning most residents of these atolls have less access to sufficient, safe, and nutritious food. Consequently, it is essential to explore alternative or additional food security measures tailored to the unique economic and agricultural conditions of these atolls. In this way, it is possible to ensure a more equitable distribution of resources and improve overall food security across the country.

Among 10 atolls with a worse poverty rate than the national one, GA and GDh atolls were excluded from further analysis as they have fishing docks by the MIFCO industry to buy fishermen's catch and have a biodiversity-rich reef, which gives them a significant advantage for fishing. The islands from the rest of 8 atolls were those whose communities extensively depend on fishing as a source of income and nutrient security. The selected 27 islands (see Table 3) are the most susceptible to development of fisheries so that additional fish storages and ice plants could be a good option for their fishermen to keep their catch fresh in seasons when they catch a lot and stock up fish for the seasons when the weather is adverse for fishing.

Table 3

Islands for modelling fish storages

No	Islands	Poverty rate	Child population, %	Population density per km^2	W_m for scenario 1	W_m for scenario 2
1	R.Agolhitheemu	18.9	33.811	876	46	38
2	R.Alifushi	18.9	38.477	2472	16	28
3	R.Kinolhas	18.9	42.369	886	20	14
4	R.Maakurathu	18.9	37.162	1671	23	33
5	R.Meedhoo	18.9	35.386	4795	28	48
6	Th.Kadoodhoo	14.4	36.292	468	48	24
7	Th.Thimarafushi	14.4	35.920	1044	41	41
8	Th.Veymandoo	14.4	38.176	2652	21	35
9	AA.Bodufolhudhoo	14.2	38.897	5227	17	39
10	AA.Thoddoo	14.2	36.102	939	41	39
11	HDh.Hanimaadhoo	12.9	35.198	623	58	40
12	HDh.Kuribi	12.9	35.908	1168	45	49
13	HDh.Naivaadhoo	12.9	36.468	1410	36	42
14	HDh.Nolhivaramu	12.9	43.854	931	28	24
15	HDh.Nolhivaranfaru	12.9	37.699	650	40	30
16	HDh.Vaikaradhoo	12.9	36.403	647	47	33
17	HA.Baarah	12.5	38.557	421	50	24
18	HA.Kelaa	12.5	33.816	475	68	46
19	HA.Utheemu	12.5	37.303	1142	41	43
20	K.Gaafaru	8.8	42.057	6141	25	49
21	K.Gulhi	8.8	34.483	7196	46	72
22	K.Kaashidhoo	8.8	37.207	648	52	40
23	L.Fonadhoo	7.8	36.012	1595	52	60
24	L.Gamu	7.8	37.785	634	54	38
25	L.Isdhoo	7.8	36.014	583	65	45
26	L.Maavah	7.8	35.976	3289	48	66
27	F.Biledhdhoo	7.1	41.986	2805	37	53
The Maldives		5.4	30.0	1284	-	-

Source: calculated by the authors based on data from [7; 28].

Following the methodology, the binary linear optimisation model presented by formulas (5) and (6) dealt with M = 27 variables. Weight coefficients W_m were defined as the total rank for each island by two scenarios. Poverty rates were ranked in descending order with the same value for the whole atoll. Child population shares were also ranked in the descending order. In case of scenario 1 a population density was ranked in the descending order while in case of scenario 2 it was done in the ascending one. It should be noted that on the one hand, scenario 1 is beneficial as it prioritises overpopulated islands so that more inhabitants from those islands could be employed in fisheries. On the other hand, scenario 2 is focused on sparsely populated islands. It makes sense because there are more room for building new fish storages and ice plants, not to mention that fishermen from other overpopulated islands will be able to move there. Binary parameters D_{km} marked neighboring islands that are not farther than 90 km from one another that complies with demands of post-harvest fish handling.

The model calculations were performed by means of Google Sheets. Scenario 1 suggested locating new fish storages and ice plants on:

– R.Alifushi,
– Th.Veymandoo,
– AA.Bodufolhudhoo.

These three are islands from the poorest atolls in the Maldives. New facilities on R.Alifushi would be accessible within R, HA, and HDh atolls. A fish storage and ice plant established on Th.Veymandoo would serve islands of Th, L, and F atolls. Whereas new facilities built on AA.Bodufolhudhoo would be used by fishermen from AA and K atolls.

Similarly, scenario 2 advised setting new fish storages and ice plants on:

– R.Kinolhas,
– Th.Kadoodhoo,
– AA.Thoddoo.

Again they are from the poorest atolls in the Maldives and would serve the same groups of atolls as in Scenario 1, i.e. R, HA, and HDh; Th, L, and F; AA and K atolls. The found islands have a lower population density by 1.5, 2.7, and 1.4 times than the national average. Therefore, they have enough space for new facilities and even for new residents who would like to be employed in the fisheries sector.

5. DISCUSSION

Figure 1a and Table 1 depict a positive trend in fish production in the Maldives. It reached 155.2 thousand tons and increased by almost 30 % compared to 2012. On average, an annual rise in the total fish catch was 2.98 thousand tons. This can be explained by mechanisation of fishing vessels, availability of ways keeping the baits alive and fresh to catch fish and increased fishermen capacity in terms of tools, equipment, and knowledge in handling and storing the fish. Maldives Industrial Fisheries Company Ltd (MIFCO) is the state-owned fishing company established with the sole purpose of creating economic opportunities for the local fishing community and to support the Maldivian economy. This company procures fish from local fishermen directly from their fishing vessels and also supports them logistically. MIFCO is a company which processes fish as canned and frozen for export purposes. In recent years they have scaled up their business into 4 processing facilities, Felivaru Fisheries Complex, Kooddoo Fisheries Complex, Kandu Oiy Giri Fish Village, and Addu Fisheries Complex. In addition, MIFCO fish shop sells different products from the above factories for the local market under MIFCO's own brand name "Fasmeeru" [29].

Figure 1b and Table 1 show a positive trend in the Maldivian fish exports with an average annual increase by 3.08 %. At present fish is the prime exported product from the Maldives which amounted to USD 175 mln in 2023. In particular, fish exports consisted of frozen fish (66 %), canned fish (24 %), and fresh or chilled tuna (8 %). A drastic increment in Maldivian fresh exports happened in 2017. This phenomenon is the result of various government measures undertaken under the Blue Economy initiative along with the support of international donor agencies such as JICA and UNDP in scaling up the fisheries sector. This includes increasing the price of a fish catch, expanding the fisheries market and supporting the local communities in growing and farming baits and bait hatcheries. These donor agencies also, train the fishermen in controlling the quality of fish products and increased support to fishermen in terms of storing and handling live bait in their fishing vessels increasing the fish catch [30]. Besides, Maldives SDFC (Small and Medium Enterprise Development Finance Corporation) provides loans to fishermen in building and developing their fishing vessels with high mechanised engines and installation of refrigerated sea water systems to help them keep their catch fresh to travel long distances and sell their catch to different fishing companies [29]. Moreover, the Maldives fisheries sector has opened to the private sector increasing the demand for fish to process and export it. Therefore, higher prices and more flexible trade conditions divert fishermen from domestic market to foreign clients who nowadays get over 70 % of the fish catch [7].

Despite the accelerated population growth in the Maldives, domestic fish consumption has been decreasing annually by 3.03 thousand tons (see Figure 1c and Table 1). Simultaneously, protein intake from fish is going down annually by 3.3 g/capita/day (see Figure 1d and Table 1). Although Maldivians are still the among leaders by fish consumption in the world, these trends are worrying since fish is the major source of animal protein in the Maldives and the ongoing decline is endangering the national food security and unbalancing a local healthy diet. For comparison other countries, e.g. Ukraine [31], rely on animal production, i.e. fisheries industry is a secondary sector. But it does not work in case of the Maldives where any negative trends concerning fishing are really critical. Indeed, fishermen report that the purchasing power of some islands is very limited as they have to offer a lower price for their catch which does not cover the daily expenses of their fishing trips. This reduces the amount of fish available for local consumption in many small island communities [32]. Another potential reason for a drop in the amount of fish consumption could be the increased price of the fish due to the high cost involved in maintaining the fishing vessels and expenses required for the ice fish storages on the fishing vessels. In addition to this, the Maldives has observed a great shift in the eating habits of the people where "Western diet" has become more common across all age groups [33]. It contradicts to the national aim to provide own food security through decreasing crucial dependency on food imports that is dangerous with regard to experienced natural disasters and pandemic restrictions. Maldivian agriculture is presented only by crop production and does not meet food security demands at all. Available animal protein, minerals and vitamins are provided by the only undiversified product – fish. The developing negative trends in fish consumption give a strong warning signal to support this sector before it is too late, i.e. to protect fisheries from becoming an insecure component of the food security system in the Maldives.

Figure 2 revealed that fisheries which contribute more to the total fish catch, in particular Dh, Th, L, GA, GDh atolls, have more stable fish production. Owing to production scale, these atolls are exemplary. It is because Maldives Transport and Contracting Company (MTCC) along with the MIFCO have been working for the development of the Ga.Kooddoo and GDh.Thinadhoo fisheries complexes by increasing the capacity of the storage facilities as well as docking MIFCO vessels so that the fishermen from these atolls can sell their fish to the vessels of these companies empowering the fishermen from the served islands [34]. Not to mention the fact that these atolls are geographically located in coastal areas rich in marine biodiversity and have oceanographic conditions that allow fishermen in these atolls to continue fishing throughout the year. In particular, GA and GDh atolls contain a surface area of over 3 thousand km^2 which is one of the largest in the world [15]. Along with the natural conditions which favour the fishermen of these atolls, the sustainable fishing methods used by all the fishermen of the Maldives which include line and pole fishing further increase the amount of fish caught by the fishermen of these atolls. The study conducted in Dh atoll, Maldives, aimed to understand the patterns of fish consumption in local households. It showed that 58 % of the respondents preferred reef fish, indicating a potential connection to the richness of marine biodiversity in the coral reefs surrounding these islands [35].

On the other hand, fisheries from atolls which have less shares in the total fish catch tend to demonstrate higher variation in fish production. In particular, HDh, N, B, AA, and especially V atolls need special scientific support aimed to bolster food security and fisheries management in those areas since they are more vulnerable to seasonal variability weather fluctuations and tuna migrations creating uncertainty and decreasing the revenue stability [36]. These small islands are susceptible to rising oceanic temperatures and damage to reefs due to bleaching that affect fish abundance and distribution. Huge damage to local reefs was also caused by the 2004 tsunami which has also been suggested as a contributor to the decline in a fish catch [36]. Coupled with the significant increase in fuel price and lack of fish storage facilities these factors drive the fishermen away from the fisheries sector in fear of not being able to cover their operational cost.

Figure 2 made it clear that atolls with more vessels, their more intensive exploitation, and more productive fishing trips are more competitive due to better resource management. It means there is a greater fishing effort exerted in these areas, with more vessels actively engaged in fishing activities leading to higher catch volumes. These atolls have better resource management practices in place compared to atolls with fewer vessels. This could involve regulations, policies, or community-based initiatives aimed at ensuring sustainable fishing practices, preventing over-exploitation of fish stocks, and maintaining the health of marine ecosystems.

Figure 3a shows a positive trend in skipjack catch but it is more volatile over months. As the total catch of skipjack is 4.5 times as large as that one of yellowfin tuna, fish storages and ice plants should be adjusted to keep increasing quantities of skipjack. Usually, skipjack fisherman travels long distance to catch fish and sell it to distant market points where sometimes they lose the value of their harvest due to deterioration of the quality owing to inadequate post-harvest practices. Hence, it is crucial for the fishermen to keep tuna in insulated containers or refrigerated holds to inhibit bacteria growth. Storage of fish also needs to be handled in a manner to increase its shelf life. It is greatly influenced by storage conditions such as temperature fluctuations, drip loss, and microbial contamination contributing to decreased shelf-life of skipjack [37].

Figure 3b demonstrates a negative trend in yellowfin tuna catch. It should be mentioned that a fishing method in case of skipjack is pole and line. Whereas this method is used for less than 40 % of yellowfin tuna and hand line fishing method is used for the rest of 60 % of yellowfin tuna catch. Yellowfin tuna is more expensive than skipjack which like skipjack demands high standards of hygiene and sanitation during handling and needs to be stored below 0°C to prevent contamination and ensure food safety.

Today fisheries laws and regulations are implemented where fishermen are allowed to fish skipjack and yellowfin tuna using sustainable and selective methods to preserve tuna stock and minimise environmental impact. This includes pole and line fishing, hand line fishing, trolling, and fishing around Fish Aggregating Devices (FADs). These methods prioritise sustainability by minimising bycatch and non-target species, aligning with the Maldives' commitment to responsible fisheries management, safeguarding marine resources for the future. Pole and line fishing, as well as hand line fishing methods, are traditional forms of fishing that have been practiced by Maldivian fishermen since ancient times. In pole and line fishing, fishermen use a fishing pole or rod equipped with a reel, which they manipulate with their hands to control casting distance and accuracy, making it suitable for targeting specific types of fish. In comparison to pole and line fishing, hand line fishing is simpler, typically involving fishermen using a baited hook attached to a line without a pole [38].

According to C. Litaay et al., pole and line fishing is valued for its sustainability due to its precise targeting of specific species like tuna, minimising unintended catches. This method of fishing entirely depends on availability and quality of baits so that it stands out for its reduced environmental impact compared to other fishing practices, as it avoids destructive techniques such as bottom trawling and large net usage. By focusing on tuna and preventing overexploitation, pole and line fishing aids in preserving fish populations and maintaining marine ecosystem balance. Its minimal habitat damage further supports overall marine health, distinguishing it from industrial methods. At the same time, the hand and line pole fishing method requires key equipment components such as baiting machines and storage devices to enhance the overall efficiency of small fishing boats [39].

The groups of atolls found by the authors' optimisation model have remarkable peculiarities and untapped potential in fisheries to be fulfilled due to new fish storages and ice plants. Indeed, R, HA, and HDh atolls have access to rich marine biodiversity with a huge surface area where oceanographic and weather conditions allow their fishermen to go fishing all the year round. When it comes to Th, L, and F atolls, they are beneficially located close to tourist resorts that have high demand for fish throughout the year. At last, AA and K atolls are characterised by very poor economic activities that is why local residents might be really interested in stable incomes.

By and large, the offered steps specified by optimisation will have a positive impact on providing food security and developing fisheries on the 31 % of the islands from 8 poorest atolls in the Maldives involved in the calculated model. Later, if interested, fishermen and domestic consumers from the rest of 69 % of the islands from AA, HA, HDh, F, K, L, R, and Th atolls would be supported by additional fish storages and ice plants.

The research recommendations for improving fisheries management cover complex measures including equalising fish trips per vessel, increasing fish catches by implementing eco-friendly fishing methods, and enhancing storages of caught fish.

6. CONCLUSIONS

Overall, the study has provided authors' insight on the status, challenges, and prospects of developing fisheries in the Maldives which strive to bolster the national food security and protect residents on the disadvantaged atolls. Being in the world top by a population density and fish consumption per capita, the Maldives recognises international principles of the Blue Economy and struggles to adapt sound management practices implemented by other countries that foster small-scale fisheries.

In light of ongoing trends, it can be argued that the total Maldivian fish catch and exports are on the promising increase and the most productive atolls demonstrate relatively stable results. However, the domestic fish consumption and protein intake from fish are going down year by year that is a warning of deteriorating nutrition and dangerous deviations from healthy diet.

The research has revealed that 10 out of 20 administrative atolls in the Maldives have a much higher level of poverty than that one in the whole country. As a result, fishermen from the disadvantaged atolls are pushed to the tourism sector to earn a living as they are the breadwinners in their families. It also correlates with improper resource management manifested through low intensity of fishing trips and a poor fish catch per vessel.

Having studied the monthly dynamics of catches by fish species, the authors of the study concluded that improving post-catch fish processing could be of great importance. Hence, it has been recommended that additional fish storages and ice plants should be established on the islands with the most vulnerable residents. The performed calculations have identified locations of such facilities by two scenarios that prioritised sparsely and densely populated islands providing services for 31 % of the most disadvantaged ones. All of the above is meant to contribute to development of fisheries management, empower local fishermen and reinforce food security in the Maldives.

7. LIMITATIONS AND FUTURE RESEARCH

To some extent, the research limitations are linked to restricted data or unavailable statistics, such as the exact quantity of fish being sold in the market or dynamics of a number of fishermen by atoll. Although this research has examined numerous aspects of providing food security with a special emphasis on efficiency of the local fishermen and fisheries sector as a whole there are some uncovered issues beyond this study.

Firstly, there are many challenges faced by the fishermen nationally because the government is unable to control the buying price of fish effectively. Despite buying skipjack and yellowfin tuna at or above international prices, the government still incurs losses. The international fish prices are significantly affected by tariff policies in major markets like the USA and European Union, which also impact locations of processing facilities. This situation leads to fishermen not making a profit despite investing essential effort, time, and money in fishing [15].

Secondly, in addition to fishing pressure, marine ecosystems are influenced by various other factors, including climate change, ocean acidification, and related biophysical effects, as well as habitat degradation and disturbances stemming from terrestrial land use, such as pollution from land-based sources and littering. Hence, securing the vitality and sustainability of fisheries demands a deep comprehension of the nuanced interplay between biology, the environment, politics, management, and governance. Fisheries confront a myriad of obstacles, and without resilient and meticulous management frameworks, these hurdles may exacerbate [40].

Therefore, by examining the named open questions future research can contribute to the development of sustainable management to tackle the multifaceted challenges which endanger Maldivian fisheries and the national food security.

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