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A Time Series Analysis Using Shannon Index of Annual Domestic Crop Production and Area Planted in Jamaica from 2007 to 2021

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Abstract **-** This paper aims to determine agricultural non-tree crop diversification with respect to crop production and area reaped in Jamaica from 2007 to 2021 using the Shannon-Wiener index. Shannon Index was calculated to determine diversification nationally and by parish. Time series analysis was done for the resulting transformed dataset and ten-year forecasts computed for national production and area reaped using linear and quadratic models. Two variables of the Shannon index, namely quantity and abundance, classified as the number of crops and the percent area reaped respectively, were regressed against the Shannon indices of area reaped and production for each parish. At the national level, a decreasing trend was unveiled for the Shannon indices for production and area reaped. This indicates that crop production and area reaped will suffer a decrease in diversification without intervention. Additionally, all parishes with the exception of Trelawny, Portland and St. Ann were diverse in crop production and area reaped. Despite moderate to high Shannon indices in most parishes, their forecasts showed decreases in production diversification in the next 10 years except for Portland, and Kingston and St Andrew which showed increase. All parishes showed decrease in diversification in area reaped with the exception of Portland, Kingston and St Andrew, St Catherine, and St Elizabeth. Regressions for Clarendon and St James were significant for the Shannon indices of production and area reaped however they showed decrease in the Shannon indices for an increase in percent area reaped implying that as agricultural land usage is increasing, the diversities in production and area reaped are still decreasing. For St James only, increasing in the number of crops will result in an increase in the Shannon indices for production and area reaped implying that as the number of crops increases, the diversification of production and area reaped increases.

Keywords**:** Shannon index, agricultural diversification, trend analysis, time series, Jamaica

1. Introduction

Biodiversity within agricultural systems is important for the conservation of plant genetic resources [1] and for supplying diverse foods needed to sustain healthy diets and prevent malnutrition [2]. On a global level, agricultural landscapes are increasingly under monocultures dominated by a few crop types (cereals and oil crops) and there is concern for the erosion of crop diversity and crop genetic resources within the context of the resilience of future agricultural systems [3].In the case of Jamaica, diversification of agriculture in the early twentieth century was characterized by the development of new crops produced on former sugar plantations and included crops like bananas, coconut and citrus to replace sugar, while coffee production was expanded at higher elevations [4]. Further diversification efforts were pursued in the early 2000s due to a combination of trade liberalization and vulnerabilities to natural disasters specifically for banana production in Jamaica, resulting in the promotion of the production of crops such as sweet potato and cassava [5].

The Shannon-Wiener index (Shannon index) has extensive application to biodiversity and ecology [6] and more recently in agricultural economics and sustainability [7]. The Shannon index reflects a community's heterogeneity based on two factors: the number of existing species and their relative abundance [8]. For this reason, it was applied to quantify the diversity in crop production and area reaped from domestic cultivation. To our knowledge, this methodology has not been conducted for Jamaica.

Agricultural diversification has been a topic discussed and recommended by experts in the Caribbean since the 1980s however little empirical research was ever conducted. This paper aims to apply the Shannon diversification index to data for production and area reaped nationally and by parish, for the period 2007 to 2021 to identify trends and make forecasts.

2. Methodology

Jamaica is the third largest island of the Caribbean Sea, located south of Cuba and west of Haiti in the North West region of the Caribbean Sea. The total area of the island is approximately 10,991 sq. km. The island consists of 14 parishes: Clarendon, Hanover, Kingston, Manchester, Portland, St Andrew, St Ann, St Catherine, St Elizabeth, St James, St Mary, St Thomas, Trelawny, and Westmoreland. Agricultural production for export and domestic use across all parishes contributes significantly to the nation's economic growth and sustainability.

The data for this paper were obtained from the Ministry of Agriculture, Jamaica from their online databases (https://www.moa.gov.jm/content/agricultural-data) and additional data required were requested formally. Area reaped (hectares) and production (tonnes) of crops were used for the period 2007 to 2021. This study focused on domestic crops that produce annually. Data were compiled yearly by parish and nationally to develop the dataset for transformation to the Shannon index. Data for Kingston and St Andrew were analysed as one parish as obtained from the Ministry's database. The categorization of crops found on the Ministry's list was maintained as it represents the standard producing crops sampled, collected and estimated for Jamaica. Quantities of other crops and specific varieties of some crops were maintained as part of the standard disaggregation of annual domestic crops. Crop not produced over the period of interest were removed from the dataset to improve precision in developing the time series for Shannon index. A maximum of 56 crops were observed over parishes for the timeframe examined. For parish level comparisons, the number of crops planted out of the 56 observed were examined.

A transformation of the datasets for crop production and area reaped nationally and by parish for the period 2007 to 2021 was done using the Shannon index. Time series analysis was then conducted to determine trends and forecasts. Based on what was found, further analysis were done using variables influencing the calculation of Shannon index.

Shannon index, H' [9] for area reaped (*AR*) and production (*P*) was computed for each parish and nationally for 2007 to 2021 using (1) and (2) below respectively:

$$H'_{AR} = -\sum_{i=1}^{S} \left(\frac{n_i}{N}\right) ln \left(\frac{n_i}{N}\right) \quad (1)$$

Where S = number of crops, n_i = area reaped for individual crops, N = total area reaped of crops

$$H'_{P} = -\sum_{j=1}^{S} \left(\frac{n_j}{N}\right) ln \left(\frac{n_j}{N}\right) \quad (2)$$

Where S = number of crops, n_j = production for individual crops, N = total production of crops.

The value of H' usually falls between 1.5 and 3.5 and only rarely surpasses 4.5 [10]. A Shannon index of over 3 is typically interpreted as diverse [7] while a Shannon index under 2 is perceived as low [11],[12].

Using Minitab, trend analysis for Shannon indices of production and area reaped was done nationally and by parish. Linear and Quadratic models were computed and compared where year was the independent variable and production and area reaped were the dependent variables.

Forecasts for the linear and quadratic models were generated for national and parish Shannon indices of crop production and area reaped. The accuracy measures, Mean Absolute Percentage Error (MAPE), Mean Absolute Deviation (MAD) and Mean Squared Deviation (MSD) of the linear and quadratic models were analysed and deductions were made from the best-fitted model. The better of the two models was determined by the smaller MAPE, MSD and MAD values.

Since the number of existing species and their relative abundance [8] are the main variables involved in determining the Shannon index, the percentage area reaped from each parish's total land space was calculated for the period under investigation. Correlations (r) were analysed for percentage area reaped and number of crops for Shannon indices of production and area reaped by parish for the period 2007 to 2021. Additionally, the percentage area reaped and the number of crops were regressed against the Shannon indices for area reaped and production for

each parish. Prior to this, the correlation between the two independent variables was investigated and the residual plots were examined for normality, independence and constant variance. Significance was tested at 5%.

3. Results

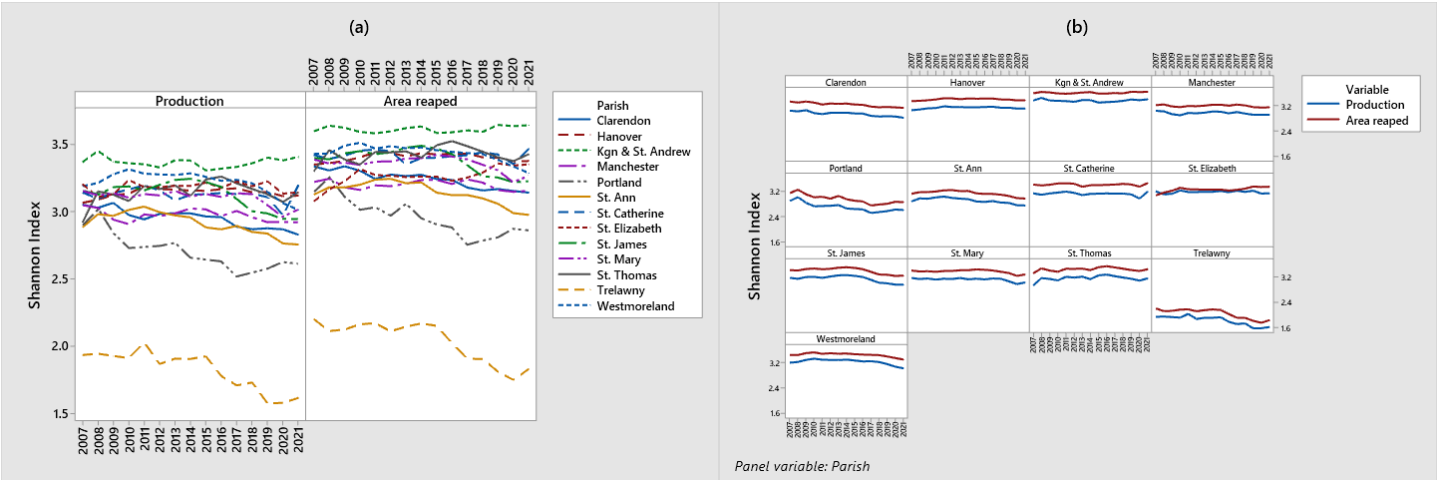


Figure 1: Shannon Indices for Production and Area Reaped by Parish for 2007 to 2021

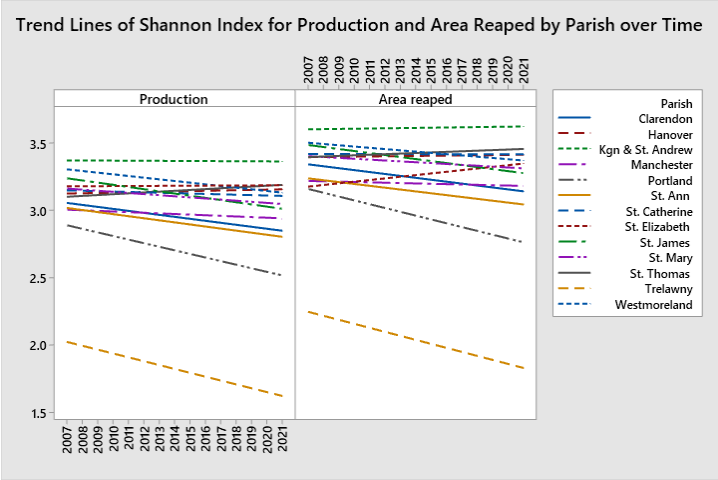


Figure 2: Trend Lines of Shannon Indices for Production and Area Reaped by Parish for 2007 to 2021

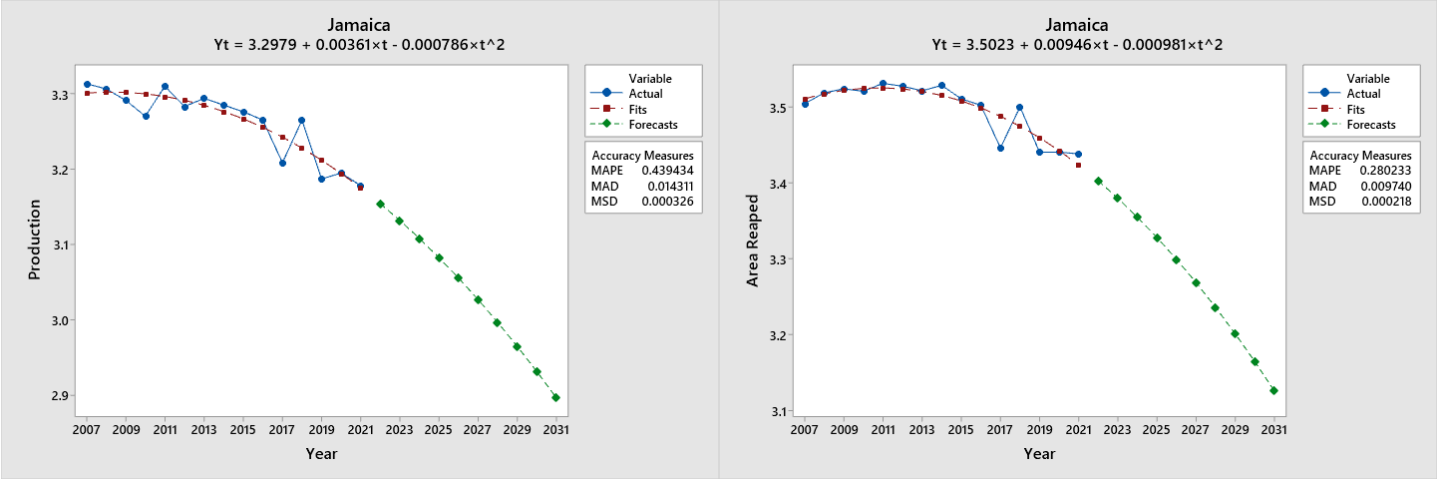
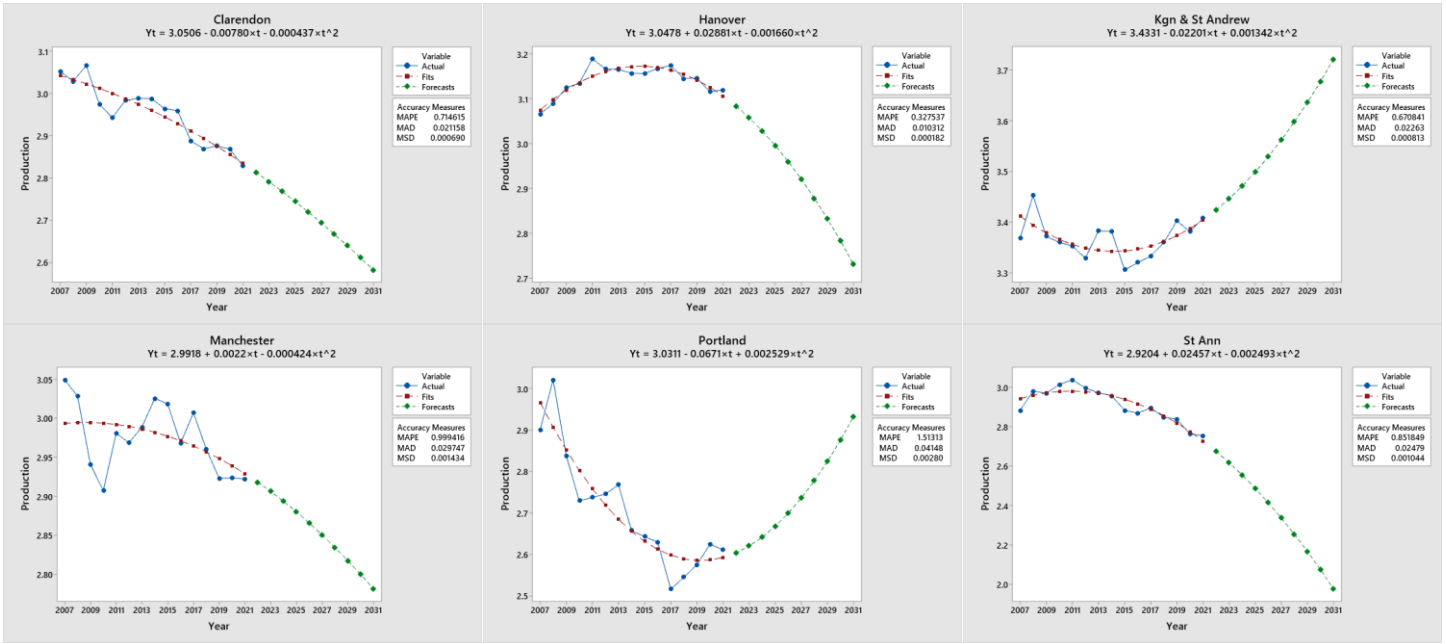


Figure 3: Trends and Forecasts for Shannon Indices of Production (left) and Area Reaped (right) in Jamaica



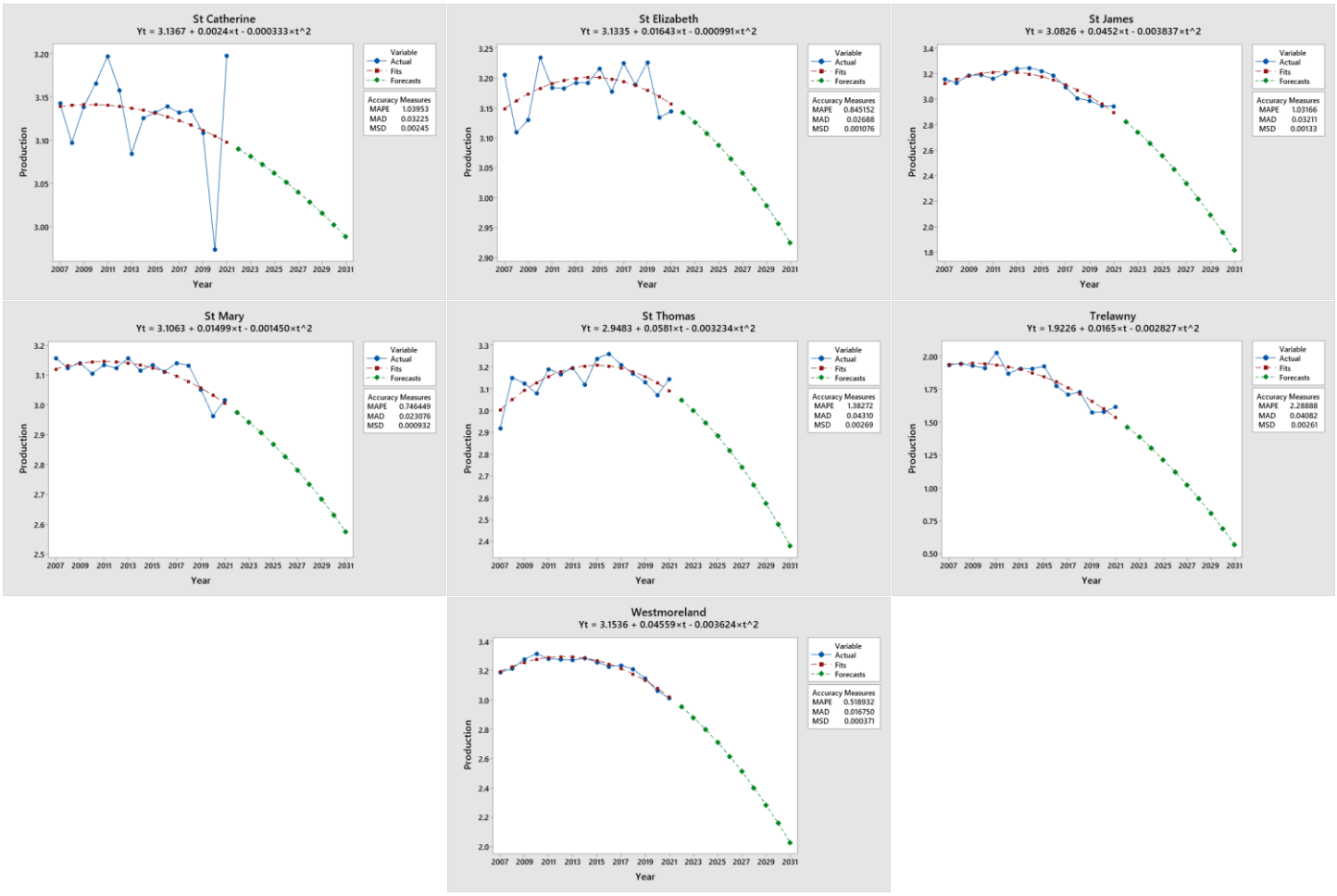
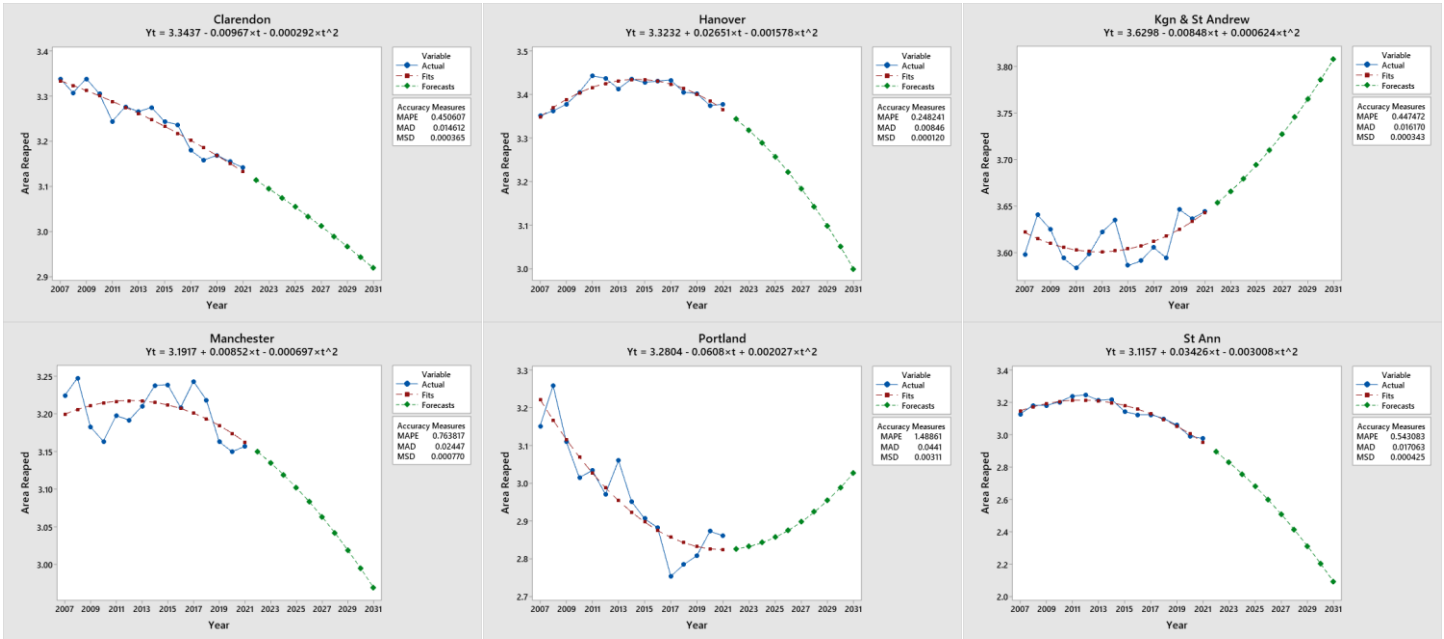


Figure 4: Trends and Forecasts for Shannon Indices of Production by Parish



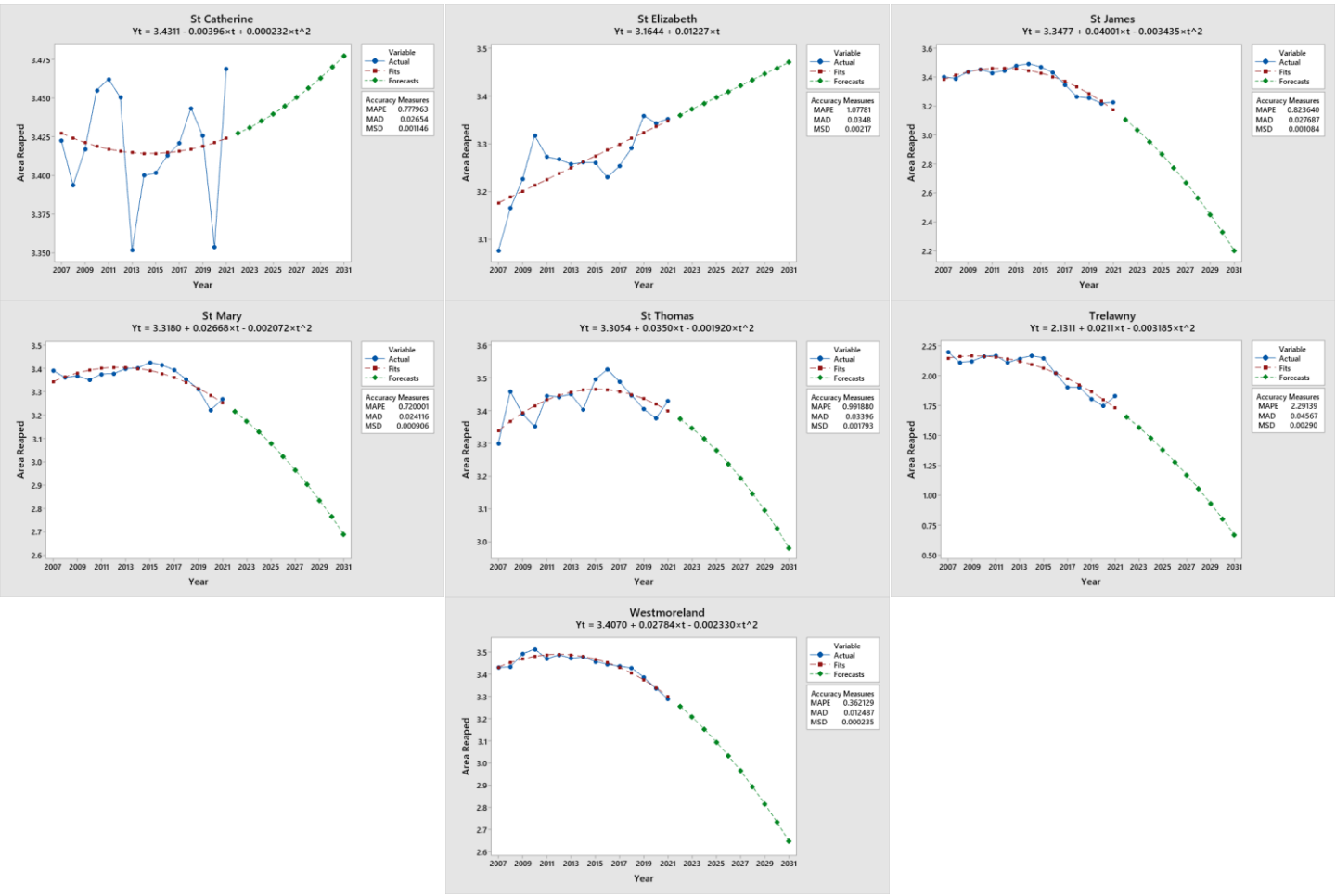


Figure 5: Trends and Forecasts for Shannon Indices of Area Reaped by Parish

Table 1: Correlation of Percent Area Reaped and Number of Crops with Shannon Indices for Production and Area Reaped by Parish

Parish	Shannon Index for Production				Shannon Index for Area Reaped			
	Percent Area Reaped		Number of Crops		Percent Area Reaped		Number of Crops	
	r	p value	*r*	p value	*r*	p value	*r*	p value
Clarendon	-0.919	0.000	-0.612	0.015	-0.934	0.000	-0.565	0.028
Hanover	0.427	0.113	-0.298	0.281	0.343	0.210	-0.184	0.512
Kingston & St Andrew	-0.166	0.554	0.117	0.678	-0.024	0.932	0.292	0.291
Manchester	-0.183	0.514	-0.17	0.545	-0.098	0.729	-0.303	0.273
Portland	-0.426	0.113	0.599	0.018	-0.360	0.187	0.574	0.025
St Ann	-0.408	0.131	-0.344	0.209	-0.374	0.170	-0.236	0.396
St Catherine	-0.039	0.890	-0.094	0.738	-0.233	0.403	0.187	0.505
St Elizabeth	0.171	0.541	0.369	0.176	0.639	0.010	0.439	0.101
St James	-0.763	0.001	-0.091	0.747	-0.771	0.001	-0.077	0.785
St Mary	-0.101	0.721	-0.197	0.481	0.190	0.498	-0.030	0.916
St Thomas	0.203	0.468	0.406	0.133	0.183	0.514	0.423	0.116
Trelawny	-0.501	0.057	-0.511	0.052	-0.449	0.093	-0.543	0.037
Westmoreland	-0.233	0.404	0.260	0.350	-0.298	0.281	0.196	0.484

Highlighted - significance at 5% level

Table 2: P values of Regression and Coefficients

Parish	Shannon Index for Production				Shannon Index for Area Reaped			
	Regression	Percent Area Reaped	Number of Crops	Regression Equation: Shannon Index for Production =	Regression	Percent Area Reaped	Number of Crops	Regression Equation: Shannon Index for Area Reaped =
Clarendon	0.000	0.000	0.398	3.408 -0.06263 Percent Area Reaped -0.00536 Number of Crops	0.000	0.000	0.781	3.505 -0.06295 Percent Area Reaped -0.00153 Number of Crops
Hanover	0.044	0.026	0.055	3.510 +0.0273 Percent Area Reaped -0.00947 Number of Crops	0.223	0.115	0.231	
Kingston & St Andrew	0.548	0.318	0.361		0.403	0.396	0.187	
Manchester	0.711	0.572	0.608		0.549	0.832	0.308	
Portland	0.068	0.869	0.092		0.091	0.911	0.083	
St Ann	0.084	0.069	0.103		0.210	0.126	0.260	
St Catherine	0.947	0.960	0.767		0.463	0.301	0.361	
St Elizabeth	0.381	0.683	0.219		0.043	0.059	0.989	
St James	0.000	0.000	0.007	2.572 -0.1690 Percent Area Reaped +0.02107 Number of Crops	0.000	0.000	0.003	2.840 -0.1571 Percent Area Reaped +0.02015 Number of Crops
St Mary	0.788	0.974	0.560		0.716	0.427	0.640	
St Thomas	0.338	0.967	0.207		0.302	0.866	0.168	
Trelawny	0.088	0.280	0.251		0.092	0.451	0.158	
Westmoreland	0.098	0.056	0.051		0.094	0.043	0.063	

Highlighted - significance at 5% level

4. Discussion

From the graphs presented in Figure 1(a), Trelawny, Portland, St Ann and Clarendon seem to be the only parish that are not highly diverse (Shannon indices less than 3) in crop production over the years. Trelawny and Portland seem to be the only parishes that are not very diverse in area reaped. When trend lines were observed (see figure 2), the Shannon indices for area reaped and production of Trelawny, Portland, St Ann and Clarendon all decreased over the period 2007 to 2021 however, Shannon indices for area reaped in Clarendon and St Ann, up to 2021, remained above 3.

Diversity in area reaped was marginally higher than production across all parishes (see figure 1b) and almost perfectly correlated to diversity in production ($r=0.988$, p value=0.000) for the time frame examined. For all parishes except St Elizabeth, correlation between Shannon indices for production and area reaped was strongly positively correlated ($r>0.80$, $p<0.000$). St Elizabeth had a correlation of zero.

Quadratic models were the preferred fit of the national level (see figure 3) and the parish level (see figure 4) Shannon indices of production evident by the smaller MAPE, MAD and MSD values. For area reaped, the national level (see figure 3) and all parish level Shannon indices (see figures 5) were fitted better by the quadratic model except St Elizabeth which was fitted better by the linear model. This was evident by the accuracy measures being smaller for the linear model.

Forecasts for the Shannon index for production (see figure 4) indicated that Clarendon, Hanover, Manchester, St Ann, St Catherine, St Elizabeth, St James, St Mary, St Thomas, Trelawny and Westmoreland will suffer a decrease in diversification over the next ten years. Trelawny, St Ann, and Clarendon have low diversification indices for production whereas the other parishes, though trending downwards still have moderate diversification indices. St Ann, St James and more so Trelawany are projected to worsen to an undiverse stage by 2031. The parishes Kingston and St Andrew, and

Portland are forecasted to increase in diversification in production in the next 10 years. Particularly Portland has been decreasing up to 2017 to low diversity stage however began to increase from 2018 and by 2031 is projected to be moderately diverse again. Kingston and St Andrew has high diversification index for production over the period 2007 to 2021 and is project to continue increasing in the next 10 years.

Forecasts for the Shannon index for area reaped (see figure 5) showed a decreasing trend for Clarendon, Hanover, Manchester, St Ann, St James, St Mary, St Thomas, Trelawny and Westmoreland. Similarly to production, some of these parishes has moderate to high Shannon indices and though decreasing, they are not forecasted to decrease to a low diversification level for area reaped. The parishes, St Ann and Trelawny, which has low diversification indices for area reaped, are projected to decrease further to an undiverse state by 2031. Parishes such as Kingston and St Andrew, Portland, St Catherine and St Elizabeth (linear model) are forecasted to increase in diversification of area reaped in the next ten years. Specifically Portland has seen a continuous decrease in diversification of area reaped however it is expected to reach a diverse state in area reaped by 2031 which it has not seen since 2013.

The year 2020 may have incurred some deviation in the forecasts for some parishes due to disruption in production and data collection as a result of the pandemic. Particularly St Catherine saw sharp decline in Shannon Indices for production and area reaped in 2020. To confirm if indeed this would have disturbed the trend, data for 2022 onwards will have to be analyzed.

Across all parishes, an increase in percent area reaped out of the total land area is seen. When correlation was tested for percent area reaped and Shannon index for production (see table 1), Clarendon (r=-0.919, p value=0.000) and St James (r=-0.763, p value= 0.001) were strongly negatively correlated indicating that as the percent area reaped increased, the diversification in production decreased. When the number of crops and the Shannon index for production were correlated, Clarendon (r=-0.612, p value=0.015) and Trelawny (r=-0.511, p value=0.052) were moderately negatively correlated and Portland (r=0.599, p value=0.018) was moderately positively correlated. When correlation was tested for percent area reaped and Shannon index for area reaped, Clarendon (r=-0.934, p value=0.000) and St James (r=-0.771, p value=0.001) were strongly negatively correlated (see table 1) implying that as percent area reaped increases, the diversity in area reaped decreases. Conversely, St Elizabeth (r=0.639, p value=0.010) had positive correlation indicating that as percent area reaped increased, the diversity in area reaped increased. When number of crops was correlated with Shannon index for area reaped, moderate negative correlation was observed for Clarendon (r=-0.565, p value=0.028) and Trelawny (-0.543, p value=0.037) and moderate positive correlation was observed for Portland (r=0.574, p value=0.025).

When percent area reaped and number of crops were used as independent variables for regression, some parishes had moderate correlation therefore the Variance Inflation Factor (VIF) were examined for each model. All VIFs found to be under 2, therefore the moderately high correlation values were not an issue in the regression models computed.

For Shannon index of production, regressions for Clarendon (p value=0.000), Hanover (p value= 0.044) and St James (p value=0.000) were significant. The percent area reaped was a significant predictor for Clarendon, Hanover and St James and number of crops was a significant for St James. For Shannon index of area reaped, regressions for Clarendon (p value =0.000), St Elizabeth (p value=0.043) and St James (p value=0.000) were significant (see table 2).

For every percent increase in area reaped for Clarendon, the Shannon indices of production and area reaped are expected to decrease by 0.06263 and 0.06295 respectively (see table 2). For St James, the Shannon indices of production and area reaped are expected to decrease by 0.1690 and 0.1571 respectively. Increasing the percent reaped over time was not successful in increasing the diversification of production and area reaped for these parishes. This could perhaps be attributed to initiatives that increase crop production on less land area which can cause large differences in evenness in the dataset. Shannon Evenness index was not calculated in this paper but is worth investigating in future work. Additionally, increasing the number of crops for St James only, will increase the Shannon indices of production and area reaped by 0.02107 and 0.02015 respectively. These results concur with the correlation tests performed. For all other parishes, both independent variables, despite being driving factors of diversification, provided no information towards predicting the Shannon indices of production and area reaped. This was evident by insignificant regressions derived for these parishes (see table 2).

5. Conclusion

Most parishes in Jamaica exhibit moderate to high diversification in production and area reaped however forecasts indicate that some will decrease in the next ten years. The two driving factors of diversification, namely quantity and

abundance represented by number of crops and percent area reaped in this study, provided no information towards predicting the Shannon indices of production and area reaped for most parishes.

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