A CASE STUDY USING SATELLITE NIGHT LIGHT LUMINOSITY

The Macro-Economic Effects of Hurricanes in The Bahamas

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Executive Summary

This paper analyses the macroeconomic effects of Hurricanes Joaquin (2015), Matthew (2016), Irma (2017), and Dorian (2019) across different islands in The Bahamas. The methodology used, based on Zegarra *et al.* (2020), uses historical night light intensity data between 2015 and 2019 and monthly GDP. The analysis is complemented by a breakdown of the direct and indirect costs by island that compiles the information in the four Damages and Losses Assessments conducted by the Economic Commission on Latin America and the Caribbean and the Inter-American Development Bank. The results suggest, first, that the year-to-year nominal growth rate in The Bahamas decreased during the month and quarter of each hurricane event, but that there was no contraction of the country's growth rate in the year of the event. However, all islands showed a significant contraction in GDP after the start of the COVID-19 outbreak, which overlapped with the effects of Hurricane Dorian. Second, large islands like New Providence and Grand Bahama experienced larger GDP contractions following the hurricanes, but no such clear pattern was obtained for the Family Islands. Third, macroeconomic recovery times to achieve pre-hurricane GDP levels took between 4-8 months on average for the four events studied. Fourth, the composition of sectors affected by the events did not seem to have a major effect on the severity of the economic shock. For all the hurricanes studied, tourism, transport infrastructure, and housing were recurrently the most affected sectors. **Based on the findings of the analysis, recommendations include the following:** (1) Make greater use of these methodologies to study the macroeconomic effects of natural disasters, supplemented by microeconomic, social, and sector-specific studies; (2) Conduct further analysis of island-specific economic drivers and post-hurricane economic effects; and (3) Promote climate change adaptation and disaster risk management to reinforce macroeconomic resilience in sectors that drive national GDP and to foster resilience in sectors and on islands.

Table of Contents

Acronyms

DaLA	Damages and Losses Assessment
DMSP-OLS	Defense Meteorological Satellite Program Operational Lines-can System
DSoB	Department of Statistics of The Bahamas
ECLAC	Economic Commission for Latin America and the Caribbean
EM-DAT	Centre for Research on the Epidemiology of Disasters' Emergency Events Database
GDP	Gross domestic product
IDB	Inter-American Development Bank
IMF	International Monetary Fund
NGDC	National Geophysical Data Center
NOAA	National Oceanic and Atmospheric Administration
PCHIP	Piecewise Cubic Hermite Interpolating Polynomial
UNWTO	United Nations World Tourism Organization
VIIRS	Visible Infrared Imaging Radiometer Suite
WTTC	World Travel and Tourism Council

1. Introduction

The Bahamas is a Caribbean archipelago country highly dependent on tourism. The country is comprised of approximately 700 islands and 2,400 cays, with a land area of approximately 13,900 km2 and 3,500 km of coastline spread over the southwestern portion of the North Atlantic. Thirty islands are inhabited and 70 percent of the population is located in New Providence, according to the 2010 Bahamas Census. The Bahamas is categorized as a high-income country, and it relies primarily on tourism for its economic activity. Tourism accounts for 43.3 percent of GDP (including direct and indirect effects), 52.2 percent of jobs, and 81.6 percent of total exports (WTTC 2019). Most tourism in The Bahamas is beach- and cruise-based (UNWTO 2021).

Due to its geography and location in the Atlantic hurricane belt, The Bahamas is extremely vulnerable to natural disasters and climate change. Approximately 80 percent of the country's land mass is within 5 feet (1.5 meters) of sea level and most of the population and economic activity are located near the coast. The country is particularly vulnerable to tropical cyclones and climate change because of the large territorial area that it is spread across, its large number of low-lying archipelagic islands surrounded by warm shallow seas, and its dispersed population. The Bahamas has been hit by 25 hurricanes over the past 25 years. Between 1963 and 2019, 14 of the most devastating hurricanes in The Bahamas occurred on average every four years, had an average impact of 5.1 percent of GDP, and affected over 29,600 people (Center for Research on the Epidemiology of Disasters 2019; ECLAC 2020b; IMF, various years); Mooney and Rosenblatt 2019).

Figure 1.

The Commonwealth of The Bahamas

Source: www.bahamas.gov.bs
Note: The Family Islands refers to all islands in The Bahamas (approximately 700 islands) excluding New Providence Island and Grand Bahama Island.

Due to climate change, increased water temperature in the North Atlantic and Caribbean will likely increase the average strength and frequency of tropical cyclones (Holland and Bruyère 2014; Balaguru *et al.* 2018). Sea-level rise induced by climate change, combined with the aforementioned characteristics of tropical cyclones, will likely exacerbate cyclone-induced storm surge and flooding going forward, thus increasing The Bahamas' exposure and risks to related natural hazards.

Although this paper focuses on the most recent events, The Bahamas has historically been hit regularly by hurricanes and tropical cyclones. Since the beginning of the 20th century, The Bahamas has been impacted by 55 hurricanes, of which 13 were high-intensity events (Category 3 and higher). This paper focuses on the four most recent Category 4 and 5 hurricanes for which a Damages and Losses Assessment (DaLA) was conducted by the Economic Commission for Latin America and the Caribbean (ECLAC) and the Inter-American Development Bank (IDB) (Table 1): Hurricanes Joaquin (2015), Matthew (2016), Irma (2017), and Dorian (2019).

Hurricane Joaquin formed rapidly and impacted the south-eastern Bahamas as a Category 4 hurricane between September 30 and October 2, 2015. Joaquin had sustained wind speeds of more than 120 mph (210 km/h) and remained stationary over several islands for more than 36 hours. The sparsely populated Acklins Island, Crooked Island, Long Island, Rum Cay, and San Salvador Island were the most affected. Prolonged high winds and storm surge resulted in widespread damage and flooding that persisted for days after the hurricane's departure. The rapid arrival of Hurricane Joaquin provided little time for warning, preparedness, or evacuation.

Hurricane Matthew impacted the primary economic and population centres of The Bahamas as a Category 3 and 4 hurricane in October 2016. Matthew had been anticipated for days, providing ample time to warn the public, prepare, and evacuate/shelter people in advance of the hurricane's landfall. Andros, Grand Bahama, and New Providence were the most affected islands. Specifically, the hurricane had the greatest effect on the country's population centres, namely New Providence (Nassau), Grand Bahama (Freeport) and the district of North Andros. Damages were mainly caused by high winds and storm surges and were exacerbated by construction practices and the presence of infrastructure and communities in vulnerable locations. Given the extensive damage to the United States, additional resources to support recovery efforts in The Bahamas were delayed (ECLAC 2020a).

Hurricane Irma impacted the Southern Bahamas islands as a Category 5 hurricane in September 2017, hitting the country on September 7 with sustained winds of 175 mph (280 km/h). It then weakened to a Category 4 storm, with sustained winds of 150 mph (240 km/h) before its centre passed over Ragged Island on September 8. Acklins, Inagua (Great Inagua), and Ragged Island in the south-eastern part of The Bahamas, as well as Bimini and Grand Bahama in the north, were the most affected. Fortunately, the country's timely warning systems allowed for the evacuation of people in advance. Most of the damage resulted from excess rainfall, storm surge, and flooding (ECLAC 2017). Ragged Island, where Irma's eye passed, was the most heavily affected. An estimated 90 percent of buildings were destroyed or severely damaged in Duncan Town. The primary cause of damage to the island was high wind, as most of the settled area is elevated above areas that were affected by storm surge. In Grand Bahama and Bimini, marine facilities and coastal houses were mostly affected from storm surges and isolated tornados.

Hurricane Dorian made landfall on Abaco on September 1, 2019, and then reached Grand Bahama as a Category 5 storm the next day. Dorian was the strongest hurricane on record to ever hit The Bahamas. The hurricane made landfall in Abaco with minimum sustained winds of 185 mph (280 km/h), then moved to the eastern side of Grand Bahama as a Category 5 storm on September 2, stalling over the island and then finally leaving the next day. The central and northern parts of Abaco were affected by hurricane force winds, storm surge, and flooding. Northern and Central Abaco and Eastern Grand Bahama were the most affected parts of these islands, and there was also some damage on the island of New Providence. Storm surge and flooding caused the most severe damage. Reconstruction was affected by the onset of the COVID-19 pandemic a few months later, which has resulted in many lives lost and a stall of economic activity across the country.

Table 1.

High-Category Hurricanes that Have Hit The Bahamas, 2015–2019

Year	Name	Category	Affected Islands
2015	Hurricane Joaquin	4	**Acklins Island**, Crooked Island, Exuma and Cays, Long Island, Rum Cay, and San Salvador Island
2016	Hurricane Matthew	4	Andros Island, **Grand Bahama Island**, and New Providence
2017	Hurricane Irma	5	Acklins Island, Andros Island, Bimini Islands, Grand Bahama Island, Inagua, and **Ragged Island**
2019	Hurricane Dorian	5	**Abaco Island, Grand Bahama Island**

Sources: Associated Press (2019); and authors' calculations.
Note: Islands highlighted in bold are the two with the greatest damage (direct costs) based on Damages and Losses Assessments.

This paper analyses the macroeconomic effects of Hurricanes Joaquin, Matthew, Irma, and Dorian in The Bahamas across different islands. The effects were reconstructed and back-analysed using historical night light intensity data between 2015 and 2019, and monthly GDP by island, prior to and immediately after each of the four hurricanes hit. This analysis is complemented with a breakdown of the direct and indirect costs of the hurricanes by island, compiling the information in the DaLAs for these four events. DaLAs provide a systematic and comparable account of the direct and indirect costs by sector related to each hurricane. They are based on the best available information obtained through government sources, interviews, and site visits. They are performed under time constraints within a few weeks after the disaster.

Section 2 of this paper presents the theoretical context of the analysis of the economic impact of natural disasters and provides a summary of the literature available on the topic.

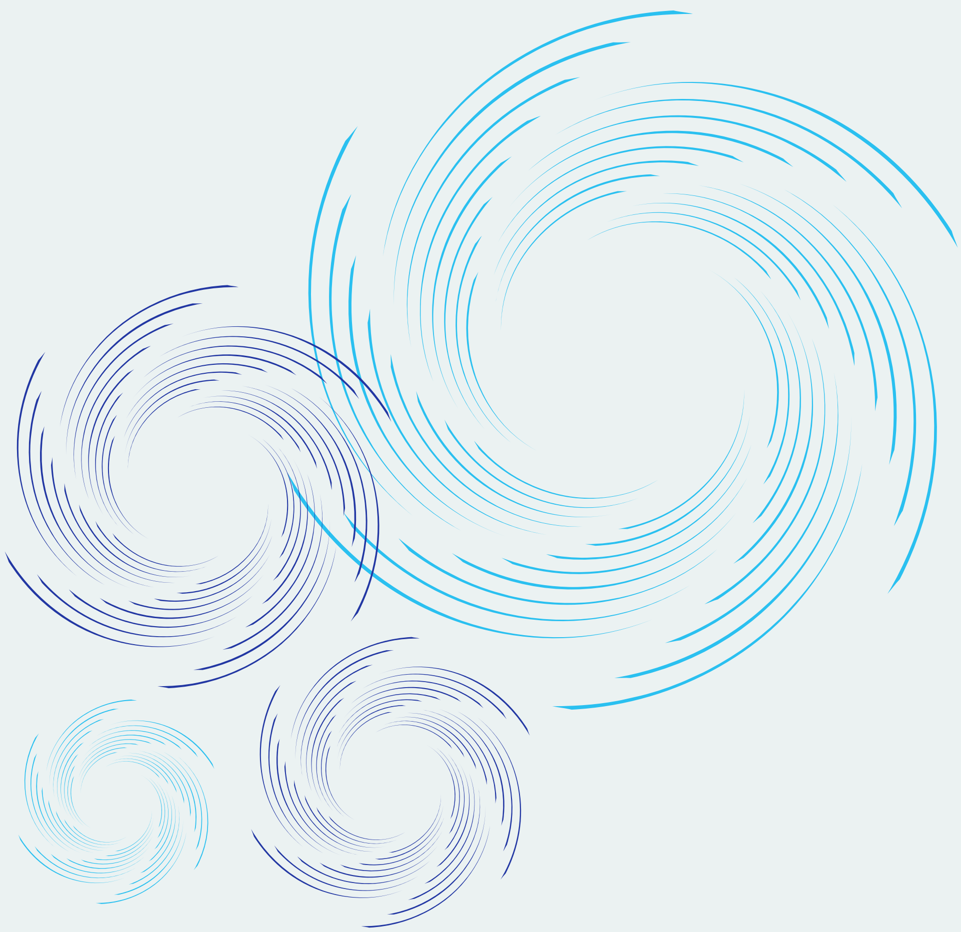
Section 3 analyses the intensity and length of the economic impact of the four hurricanes on The Bahamas using the satellite data on light intensity. It also presents a breakdown of costs based on the DaLAs. The final section presents the conclusions of the paper.

2. Theoretical Context

The literature on the economic impact of natural disasters has grown quickly in recent years. Most existing empirical evidence focuses on the short-run effects of disasters – up to three years – with an overall consensus that natural disasters hinder per capita income and growth (Felbermayr and Gröschl 2014; Raddatz 2009; Strobl 2012). Noy (2009) further analyses some of the structural and institutional traits of a country that exacerbate the negative effect of disasters, concluding that countries with higher per capita income, better institutions, a higher literacy rate, greater openness to trade, higher levels of government spending, more foreign exchange reserves, and higher levels of domestic credit and less open capital accounts are better able to withstand an initial shock and more effectively prevent further spillovers. This contrasts with earlier work by Albala-Bertrand (1993) and Skidmore and Toya (2002), who occasionally find positive impacts on growth from natural disasters. Loayza *et al.* (2012) highlight that these positive impacts may be recorded for smaller disasters (reflecting the post-disaster reconstruction stimulus), whereas large disasters always have negative effects on the economy in the short run. Beyond growth, natural disasters have also been shown to hinder investment and savings and lead to higher debt accumulation.

There is less consensus on the long-run effects of natural disasters – usually more than five years. There is also a scarcity of research in this area, partly due to the difficulty of constructing appropriate counterfactuals. The scarce evidence also shows mixed results. On the one hand, some studies identify a rebound in economic activity due to rebuilding and the resumption of economic activity, which can erase losses from a disaster. On the other hand, Noy and Nualsri (2007) find negative growth impacts of natural disasters with high casualty numbers but no significant effects of disasters damaging the capital stock. Similar results are reported by Jaramillo (2009). Crespo Cuaresma, Hlouskova, and Obersteiner (2008) attempted to investigate this creative destruction hypothesis empirically and concluded that it most likely only occurs in countries with high per capita income. Finally, other studies found no statistically significant effects of natural disasters on growth (Raddatz 2009). Cavallo *et al.* (2010) conclude that long-run effects on growth only occur if the natural disaster is followed by a radical political revolution (such as the Islamic Iranian Revolution of 1979 or the Sandinista Nicaraguan Revolution of 1979). However, Raddatz (2009) finds that climatic disasters have a negative long-run impact on economic growth, but highlights that most of the output cost of those events occurs during the year of the disaster. There is also a fairly broad body of empirical evidence that generally finds negative and delayed recovery effects in the aftermath of natural disasters. For example, Coffman and Noy (2012) analysed the long-term impact of Hurricane Iniki (1992) on the economy of a Hawaiian island and found that it took almost seven years for the island's economy to return to its pre-hurricane per capita income level, and that the island never fully recovered from the disaster's out-migration effect.

Traditional data sources and methods for studying natural disasters have limitations. The vast majority of existing studies rely on the Centre for Research on the Epidemiology of Disasters' Emergency Events Database (EM-DAT). However, as Strobl (2012) argues, the EM-DAT data are collected from various sources and there is potential that the dataset may have measurement divergences. Moreover, most empirical studies of the growth effects of natural disasters regress GDP growth on a number of control variables (such as the saving rate, fertility, or human capital) and add a measure of disaster frequency or severity to the estimation equation. As the effect of natural disasters on economic growth might work through these control variables, an "overcontrolling problem" is likely to occur, which might result in insignificant effects (Dell, Jones, and Olken 2014).



3. Estimating the Macro-economic Effects of Hurricanes in The Bahamas

3.1. Methodology

This study presents a novel approach to identify the economic effect of hurricanes in The Bahamas through the use of satellite night light data. The methodology follows numerous research studies using luminosity measured from space to proxy for economic activity, where the brightest areas depict locations of high activity (Amavilah 2018; Pinkovskiy and Sala-i-Martin 2016; Nordhaus and Chen 2015; Henderson *et al.* 2012). Moreover, the IDB has used luminosity data to analyse the beneficial effects of coastal infrastructure in Barbados (Corral *et al.* 2018) and to study the patterns of poverty and inequality in Haiti (Pokhriyal *et al.* 2020). This study uses the variation in the average brightness of the night lights on each island to estimate the variation of economic activity before and after hurricanes hit The Bahamas.[1]

To estimate the effect of hurricanes on the Bahamian economy, datasets were constructed to generate an economic activity index (Zegarra *et al.* 2020). First, a database with satellite imagery of luminosity was constructed for The Bahamas with data obtained through the National Geophysical Data Center of the U.S. National Oceanic and Atmospheric Administration (NOAA).[2] Second, a population density series was developed for each island by applying the Piecewise Cubic Hermite Interpolating Polynomial to the population censuses of 1980, 1990, 2000, and 2010. Third, luminosity levels and population density parameters of a production function were estimated. Fourth, a proxy of the GDP by island for 2013 was estimated, taking into account that 2013 is the latest available household survey that reports income and expenses. Finally, an economic activity index was generated considering the base year and thereby estimating the GDP for the entire period of analysis (see Annex 1 for more details on the data and methodology). A similar approach to the methodology was utilized to estimate a monthly economic activity index by island. The monthly economic activity index was calculated for the period from January 2013 to May 2020, taking into account that monthly basis maps are only available from 2013 onward A quarterly basis economic activity index was estimated by aggregating the results of the monthly-basis economic activity index by calendar-year quarters.

3.2. Results

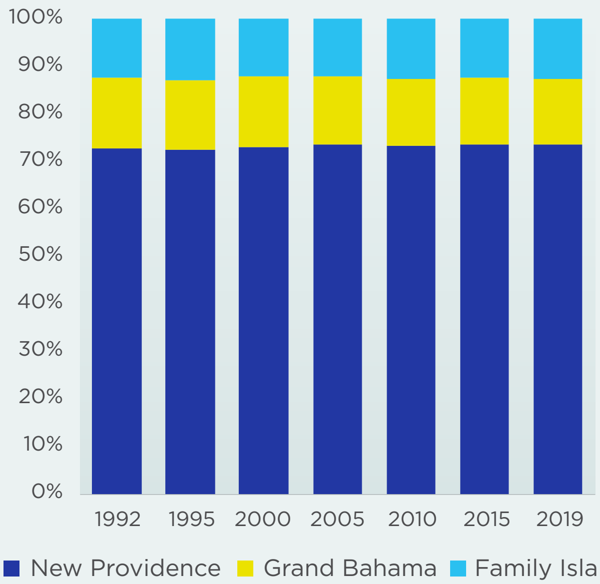
The disaggregation of GDP by island confirms that New Providence contributes on average three-quarters of The Bahamas' GDP and has the strongest effect on the trajectory of national GDP. New Providence's weight on national GDP has averaged 73.4 percent of the total over the past 28 years. Comparatively, Grand Bahama and the Family Islands accounted for 14.3 percent and 12.3 percent of GDP, respectively, over the same period (The Family Islands refers to all islands in The Bahamas (approximately 700 islands) excluding New Providence Island and Grand Bahama Island). On the Family Islands, 80 percent of GDP is concentrated in five islands (Abaco, Andros,

1. As an example, Annex 2 shows maps of the night lights captured by satellites in Abaco and Grand Bahama before, during, and after Hurricane Dorian struck the islands. The images for May 2020 show that the lights had not fully recovered from their pre-hurricane levels in 2019.
2. Recently, NOAA discontinued the publication of a group of products, including the Visible Infrared Imaging Radiometer (VIIRS) night light maps that were used in this study. Those maps are now publicly available through the academic sector at the Colorado School of Mines at https://payneinstitute.mines.edu/eog/.

Eleuthera, Exuma-Cays, and Long Island), with the greatest GDP share shifting over time between various Family islands. As seen in Figure 2, the weight of New Providence on national GDP increased, from 72.8 percent in 1992 to 73.8 percent in 2019. Similarly, the Family Islands increased their GDP share from 12.2 percent in 1992 to 12.4 percent in 2019.[3] Comparatively, Grand Bahama's share has declined from 15 percent in 1992 to 13.8 percent in 2019. This downward trend has sharpened since 2016 and would suggest that recovery and reconstruction efforts after Matthew (2016), Irma (2017), and Dorian (2019) were not sufficient on this island to enable it to recover to the pre-hurricane growth trajectory, reducing the potential growth of the economy. These types of effects have been studied in Hsiang and Jina (2014), Lee, Zhang, and Nguyen (2018), Hochrainer (2009), and IDB *et al.* (2004). Comparatively, as seen in Figure 3, the islands of Abaco and Exuma-Cays increased their share of GDP; while the islands of Andros, Eleuthera, and Long Island reduced their share. For example, Abaco increased its share in the GDP of the Family Islands from 23.2 percent in 1992 to 30.2 percent in 2019, while Andros's share declined from 21.5 percent in 1992 to 13.8 percent in 2019. In the case of the Family Islands, there is therefore no clear pattern relating the incidence of hurricanes to the share of the islands' economic activity on GDP.

Figure 2.

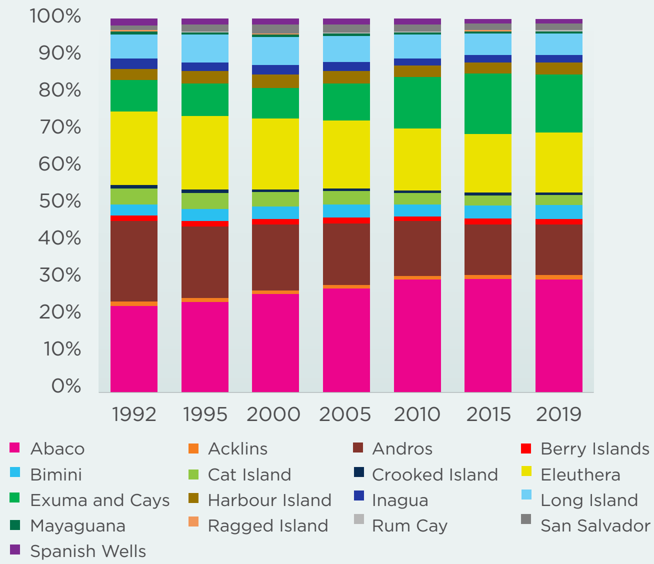
Regional GDP as a Share of Total GDP in The Bahamas, 1992–2020



Source: Prepared by the authors based on the methodology and databases explained in Annex 1.

Figure 3.

Family Island GDP as a Share of Total Family Islands' GDP, 1992–2020



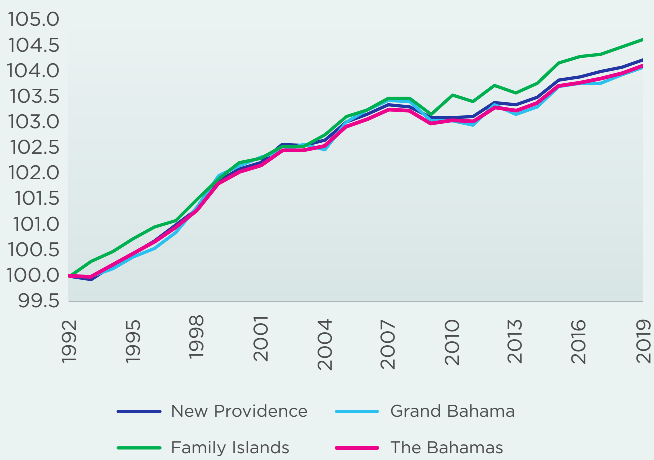
Source: Prepared by the authors based on the methodology and databases explained in Annex 1.

3. The Family Islands are made up of 17 administrative regions.

Figures 4 and 5 show the dynamic evolution of GDP between 1992 and 2020.[4] Overall, The Bahamas has had a positive growth trajectory since 1992 that decelerated from 2000 onward. Grand Bahama in particular shows stagnating growth trend since 2001 (except for a period between 2004 and 2007), compared to New Providence, the Family Islands, and The Bahamas as a whole (Figure 4). Of the Family Islands, Exuma-Cays has had the strongest growth trajectory since 1992, followed by Abaco (Figure 5). Interestingly, both Grand Bahama and the Family Islands had a reduction in GDP growth in 2016, which is not seen for New Providence, coinciding with the arrival of Hurricane Matthew. The figure also suggests that, despite the damage and losses due to Hurricane Dorian in 2019, New Providence, Grand Bahama, and the Family Islands experienced positive growth rates for that year. This could be explained by the significant increase in tourist arrivals in 2019 with respect to previous years (both for stopovers and cruise passengers), which could have crowded out the negative effect of the hurricane. Figure 5 suggests that there is no discernible effect of hurricanes on the growth trajectory of individual islands within the Family Islands. For example, Hurricane Irma in 2017 had no negative effect on most of the islands that are listed in Table 1, which would seem counter-intuitive.

Figure 4.

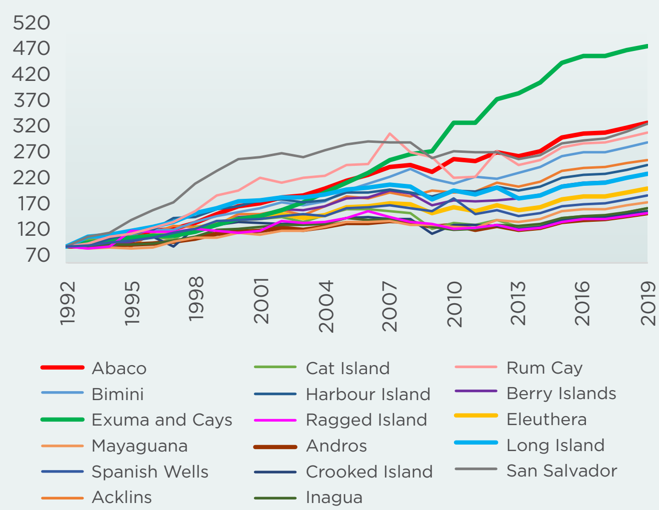
Evolution of Nominal GDP in The Bahamas, 1992–2020 (Index, 1992 = 100)



Source: Authors' calculations based on the methodology and databases explained in Annex 1.

Figure 5.

Evolution of Nominal GDP in the Family Islands, 1992–2020 (Index, 1992 = 100)

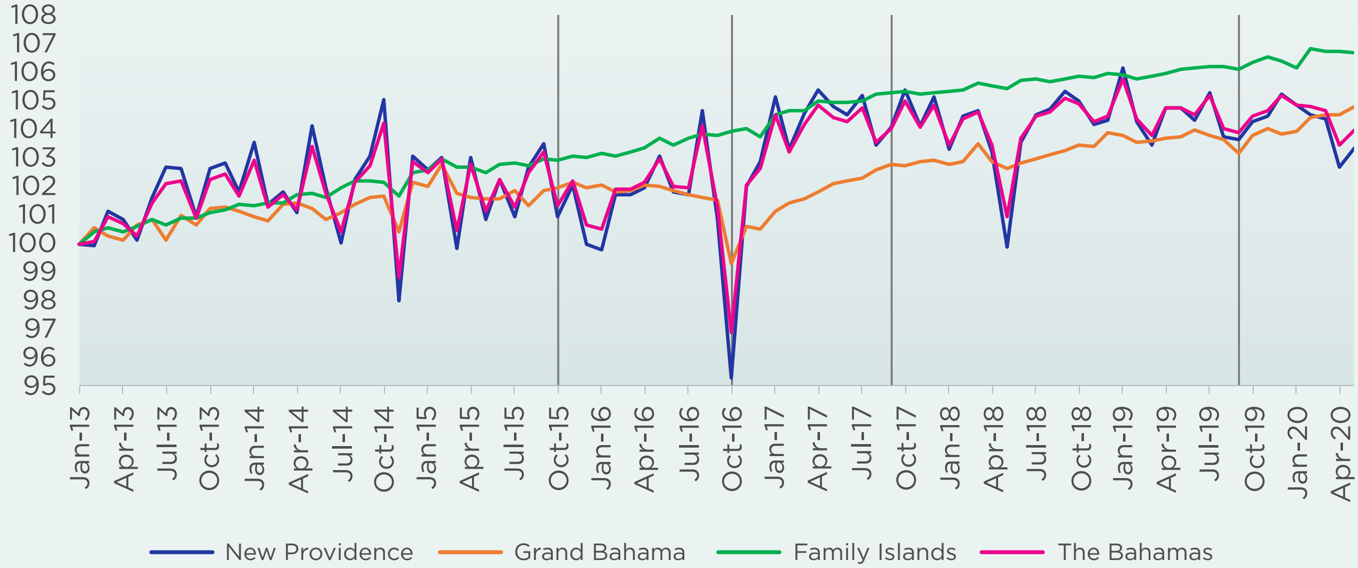


Source: Authors' calculations based on the methodology and databases explained in Annex 1.

4. These series are indexed to 1992.

Figure 6.

Monthly GDP of The Bahamas, New Providence, Grand Bahama, and the Family Islands, 2013–2020 (Index, January 2013 = 100)



Source: Authors' calculations.
Note: Vertical lines correspond to the month of occurrence of Hurricanes Joaquin (2015), Matthew (2016), Irma (2017), and Dorian (2019).

An analysis using monthly data also yields mixed results. Figure 6 shows indexes of the evolution of GDP for The Bahamas, New Providence, and the Family Islands between January 2013 and May 2020.[5] The monthly data do seem to show a negative effect from three out of the four hurricanes for all sets of islands. There is a slight negative effect for larger islands, such as New Providence and Grand Bahama. However, this effect does not seem to be present for the Family Islands. As with the yearly series, the results suggest that the path of GDP of New Providence is a strong determinant of the overall outcome of the country as a whole. The series also show great levels of seasonality due to tourist activity (with the exception of the Family Islands).[6]

Overall, islands experience a decrease in the year-to-year nominal growth rate during the month and quarter of a hurricane impact event, but do not show a contraction of the growth rate in the year of the event. As seen in Table 2, given the yearly frequency of hurricanes, the year-to-year growth rates appear to reflect the cumulative effects of the events, which do not appear to have a substantial effect on GDP.

New Providence and Grand Bahama experience larger GDP contractions following major hurricanes than the Family Islands (Table 2). On average, the Family Islands showed positive GDP growth rates after Hurricanes Joaquin, Matthew, Irma, and Dorian. Excluding Dorian, The Bahamas takes an average of 4.5 months to economically recover to its pre-hurricane GDP levels.[7] The process of macroeconomic recovery (understood as a return to the pre-hurricane GDP level) has not been the same for each hurricane and has ranged from four months after Hurricane Irma to eight months after Hurricane Matthew. Moreover, the

5. The methodology to estimate these series is described in Annex 1.
6. In The Bahamas, the high season for tourism runs from December to May, when most tourists visit the archipelago. The rest of the year is hurricane season, when there is a greater chance that the islands will be hit by tropical cyclones.
7. The average length of time for recovery from Hurricane Dorian is not included because it overlaps the effects of the COVID-19 crisis. According to our estimates, Grand Bahama recovered its pre-hurricane levels in January 2020, but its GDP dropped below hurricane levels after the pandemic started.

macroeconomic recovery time and the effect of hurricanes on growth vary across islands. This process seems to depend on the size of the economy of each island, the sectors and businesses present, population movement, recovery plans, and political decisions. For instance, it took around two months for the Family Islands affected by Hurricane Joaquin to return to their pre-disaster GDP level, while for Grand Bahama it took six months for that recovery after Hurricane Matthew. It should be noted that the time for GDP to return to its pre-hurricane levels may not reflect physical infrastructure, community, micro-economic, social, and livelihood recovery times for The Bahamas as a whole or for any individual island.

Table 2.

Effect of Hurricanes in The Bahamas

		Nominal Growth Rate (year-over-year; percent)		
		Year	Quarter	Month
Joaquin	New Providence	2.1	-1.0	-3.9
	Grand Bahama	-1.7	0.6	0.3
	Family Islands (6)	0.8	0.8	0.6
	The Bahamas	**0.7**	**-0.6**	**-2.8**
Matthew	New Providence	1.5	-1.0	-5.7
	Grand Bahama	1.4	-1.9	-2.6
	Family Islands (1)	2.6	0.9	1.0
	The Bahamas	**1.6**	**-0.9**	**-4.4**
Irma	New Providence	2.3	1.8	3.2
	Grand Bahama	0.0	0.9	1.3
	Family Islands (5)	0.7	1.5	1.5
	The Bahamas	**1.8**	**1.6**	**2.7**
Dorian	New Providence	3.3	-0.6	-1.6
	Grand Bahama	3.2	0.4	-0.1
	Family Islands (1)	3.5	0.9	0.8
	The Bahamas	**3.2**	**-0.3**	**-1.2**
Average	New Providence	2.3	-0.2	-2.0
	Grand Bahama	0.7	0.0	-0.3
	Family Islands	1.9	1.0	1.0
	The Bahamas	**1.8**	**0.0**	**-1.4**

Source: Authors' calculations.
Note: Islands in italics are those impacted by the hurricane, with the number in parentheses indicating the number of Family islands impacted.

8. It is one thing is to return to pre-hurricane levels of monthly activity; it is another to return to the pre-hurricane trend. The latter does not seem to have been the case, and as a result there is still lost growth (ceteris paribus).

The economic indicator results presented in this section suggest that hurricanes disrupt the economic activity in the short term (<5 years), yet other methodologies would be needed to assess long-term effects (>5 years). Although the analysis finds positive annual growth rates in the year of these events, The Bahamas suffers significant damage and losses after natural disasters. It takes years to recover, especially if damage is incurred to the economic centres of New Providence and Grand Bahama. It also takes longer to recover when the events are closely spaced in time. There are also substantial budget requirements to cover hurricane-related expenses that involve redirecting government and private resources that could have been used for other initiatives to increase productivity or foster development. This would also have long-term investment, debt, and growth effects on the country. A counterfactual scenario on the growth rate, which is beyond the scope of this paper, could provide a more accurate estimate of the loss in growth due to hurricanes. Future research could aim at building such counterfactual scenarios at the island level to quantify these kinds of effects.

Based on the results presented in this section, Bahamian islands, particularly larger ones, show an economic contraction in the month or quarter of the disaster event, but this effect dissipates in the annual estimates. Using yearly data, New Providence and Grand Bahama do seem to show modest changes in their GDP weight and growth trajectories that could be associated with recent hurricanes. However, no such evidence seems to be available for the Family Islands. Using monthly data, the analysis also finds a slight negative effect for larger islands such as New Providence and Grand Bahama, but no discernible effects for the Family Islands. Finally, when economic contractions for the month, quarter, and year of the event are compared, the analysis finds more prevalent negative effects for the month and quarter but not for the year. The reasons for this are complex and require more disaggregated data by island to conduct a quantitative analysis using counterfactual scenarios. For this reason, the following paragraphs present various hypotheses that could help explain these results.

Tourism flows could be offsetting the effect of the natural disaster in yearly estimates. Tourist arrivals, which are comprised of foreign air arrivals and cruise passengers, are highly correlated with the index on economic activity for The Bahamas. In particular, cruise passenger trends are highly correlated with the index on economic activity in the Family Islands (87.9 percent),[9] New Providence (87.1 percent), and Grand Bahama (60.4 percent) (Annex 3).[10] Overall, cruise passengers increased at an average pace of 3.5 percent from 1998 to 2019. New Providence hosts one of the world's busiest cruise ship ports and receives around 38 percent of the first port-of-entry cruise passengers who visit the country.[11] The Family Islands show the largest average growth rate of cruise passengers (9 percent) compared to New Providence (4.9 percent) and Grand Bahama (2.2 percent).

Looking at historical arrivals data, tourism arrivals do not fall in the years covered in this study – between 1998 and 2019, tourist arrivals only contracted during the 2008–2009 global financial crisis (Annex 3). There also seem to be substitution effects across islands, which could mitigate the overall tourism effect for the whole territory. For example, the number of cruise passengers declined in 2015 in New Providence, but increased in Grand Bahama, suggesting substitution of tourism demand between these destinations. Qualitative evidence would suggest that this can also happen at a regional level. For example, numerous Caribbean islands were impacted by back-to-back hurricanes in 2017 (Hurricanes Irma and Maria). While The Bahamas was hit by Irma, the tourism sector in New Providence and Grand Bahama did not suffer major damage. Thus, it is possible that tourist and cruise ship travel from other Caribbean island destinations may have been redirected to The

9. Due to the limited availability of data on tourist arrivals, the estimates on correlations for the Family Islands only include Abaco, Andros, Berry Islands, Bimini, Eleuthera, Inagua, Long Islands, and San Salvador.
10. However, the correlations with foreign air arrivals show mixed results. While New Providence (70.7 percent) and the Family Islands (82.3 percent) show a positive correlation between foreign tourist arrivals and the index on economic activity, Grand Bahama (-80 percent) shows a negative correlation. Over the years, the number of cruise passengers has outweighed foreign air arrivals. In 1998, half of the visitors were cruise passengers, whereas in 2019 they represented 75 percent of tourist arrivals.
11. Average share of yearly arrivals from 2015–2019.

Bahamas, with a positive effect on GDP. Annex 3 also reveals that the Family Islands have experienced a sharp increase in cruise passenger arrivals since 2017, suggesting that this effect could be offsetting the effect of hurricanes in recent years.[12] Strong tourism promotion campaigns following natural disasters, and the authorities' close coordination with resort/hotel, cruise ship, port, and aviation operators, could have been factors behind these trends. Therefore, rising tourism arrivals in recent years, irrespective of natural disasters, could have overcome the negative economic effect of hurricanes.

Highly correlated monthly economic activity indexes among the Family Islands could mitigate the economic effects of disasters on some of these islands. The results suggest that the monthly index of economic activity for New Providence is positively and significantly correlated with the indexes in Grand Bahama and Harbour Island, but not significantly correlated with those of the rest of the Family Islands. The correlation matrix also shows that Grand Bahama is negatively and significantly correlated with the Family Islands. Although still relatively small, economic activity on the Family Islands is increasing and is positively correlated among the islands, likely because of island-hopping services offered both to resort-based and cruise passengers. The mechanism behind these correlations can be explained by two patterns: (1) most of the country's economic activity is concentrated in New Providence, and (2) economic activity in the Family Islands is highly connected.

Regarding the first pattern, most resort and hotel-based tourism is concentrated in New Providence. Despite representing a lower proportion of tourist arrivals, this concentration generates more international tourism receipts compared to cruise-based tourism.[13] For example, in 2019, resort and hotel-based tourists represented only one-fourth of total tourist arrivals, but those visitors spent more time (an average length of stay of 6.4 days), they accounted for more more total expenditure (US$3.73 billion), and a higher average expenditure per tourist (US$2,070).[14] In comparison, cruise passengers, who account for 75 percent of tourist arrivals, accounted for total expenditure of US$393 million and an average expenditure per cruise-based tourist of US$72 (UNWTO 2021). In addition, New Providence concentrates around half of the country's cruise-based tourism.[15] As a result, tourism activity in New Providence likely represents a large component of the value added in the economy.

With respect to the second pattern – that economic activity in the Family Islands is highly connected – tourists can travel across the islands through arranged boat tour packages, ferries, and short air trips. These services are predominantly used for daytrips, with tourists spending most of their stay in New Providence resorts and hotels.

The economic effect of hurricanes could be related to the type of infrastructure and sectors affected by the event. If infrastructure is affected in key sectors of an island's economy, the economic effects are likely to be larger. Recovery and resumption of business activities could also be delayed as insurance claims are settled and subsequent repair/reconstruction works are undertaken. Yet in the case of Family Islands, even if key sectors are affected, high levels of correlation and substitution effects (particularly among the Family Islands themselves) could provide relief from high direct and indirect costs associated with extensive losses and damages due to a natural disaster. Heavy and extensive damage to a Family Island may shift economic activities and population to other islands, stimulating GDP activity on those islands, combined with a surge of physical and financial resources to the affected island to support recovery activities. To offer greater insight on this point, the next section uses a review of the DaLAs

12. These results only run up to 2019, before the COVID-19 crisis.
13. International tourism receipts are expenditures by international inbound visitors, including payments to national carriers for international transport. These receipts include any other prepayment made for goods or services received in the destination country.
14. Stopovers are defined as persons staying for 24 hours or more. Hotel visitors help to make up the stopover visitors.
15. In 2019, New Providence received 78.4 percent of foreign air arrivals (visitors who come to the destination by air, which may include stopover visitors, day visitors, and transit visitors) and 51.7 percent of sea arrivals (visitors who come to the destination by sea, i.e., cruise arrivals and boaters/yachters). Most hospitality capacity was also concentrated in New Providence (79.4 percent of available rooms). Grand Bahama accounted for 3.1 percent of foreign air arrivals, 8.5 percent of sea arrivals, and 9.1 percent of the available rooms in the country. The outer islands accounted for 18.5 percent of foreign air arrivals, 39.8 percent of sea arrivals, and the remaining 11.5 percent of rooms (UNWTO 2021).

to provide an overview of the estimated costs, sector effects, and characteristics of each of the four major hurricanes that are the subject of this paper.

3.3 Direct and Indirect Costs of Hurricanes: A Typology of Damage and Losses

This section breaks down the volume and composition of costs incurred in each of the four hurricanes, distinguishing between direct and indirect costs. Pelling, Özerdem, and Barakat (2002) and ECLAC (2003) introduced a typology of disaster impacts used by Cavallo *et al.* (2010) that distinguishes between direct and indirect damage due to natural disasters. Direct damage includes damage to fixed assets and capital, raw materials, extractable resources, and morbidity and mortality that is a direct consequence of the disaster. Indirect damage is related to subsequent economic activity that cannot take place due to the disaster and the redistribution of resources in the aftermath of the disaster.

Costs are calculated based on the DaLAs published by ECLAC and the IDB. ECLAC is one of the main international actors in conducting post-disaster assessments,[16] and ECLAC and the IDB completed four comprehensive and publicly available DaLAs in The Bahamas following the four major hurricanes that are the subject of this study: Joaquin, Matthew, Irma, and Dorian. These assessments estimate disaster impacts and costs as well as post-disaster sector-specific funding needs, and also provide recommendations for recovery, reconstruction, and short- and long-term disaster risk reduction and management. The methodology includes an estimate of the effects of the disaster on assets (damage) and economic flows (losses and additional costs). Other organizations, such as the World Bank, have also developed damage assessment methodologies, but this study uses ECLAC's assessment methodologies due to the availability of consistent and methodologically comparable assessments for The Bahamas for the four hurricanes.

The DaLA methodology breaks down the impact of natural disasters into damage, losses, and additional costs. The damage assessment estimates the effect of the disaster on assets, expressed in monetary terms. These assets include physical assets (such as buildings, installations, machinery, furnishings, roads, etc.) and stocks of final or semi-finished goods, raw material, materials, and spare parts.[17] We equate damages to direct costs, as defined in Cavallo & Noy (2009). Losses are goods that go unproduced and services that are unprovided during the period between the disaster and full recovery or reconstruction. For example, harvests might be reduced, industrial production might decline, or revenues might be foregone.[18] Losses can take place due both to asset damage, and thus be longer term, and to temporary activity disruption. For example, one result of the disaster may be in the form of additional spending.[20] The estimates are obtained by comparing the outlook after the disaster with a baseline that represents the counterfactual evolution of each sector if the disaster had not occurred.[20] These additional costs are not associated with the definitions used by the rest of the literature and are therefore not included in this section.

The DaLA methodology provides rapid initial estimates of the damage and losses with recommended actions to inform disaster response and strategic planning. First, these assessments provide an early initial baseline estimate of damage and losses to approximate the scale of the disaster and the initial response/recovery resources needed for each sector, based on the best available information at the time of the field assessment. The aim is for governments to then perform additional detailed assessments to track and predict medium- and long-term costs. Second, these

16. Since 1972, ECLAC has participated in 90 assessments of the social, environmental, and economic effects of disasters in 28 countries in Latin America and Caribbean. The agency has also published three methodological handbooks on the estimation of damage and losses from disasters.
17. Damage is expressed in monetary terms estimated using the physical scale of the effect and a price to convert it into a value. Damage is also measured relative to a baseline or pre-disaster situation, which is constructed using pre-disaster information on the assets of different sectors.
18. Losses are a dynamic measure of flows, and their repercussions may persist over a length of time spanning beyond the time of the valuation and could therefore be underestimated in the DaLA.
19. This includes additional spending associated with managing the emergency.
20. National accounts treat these flows differently, as additional expenditures represent a temporary increase in the intermediate consumption of a sector for a good or service restoration, which reduces its value added.

Table 3.

Comparisons between the Terminology Used in Cavallo & Noy (2009) and the Economic Commission for Latin America and the Caribbean in its Damages and Losses Assessments (DaLAs)

ECLAC DaLA Terminology	Cavallo *et al.* (2010) Terminology
Damage	Direct costs
Losses	Not included or used
Additional costs	Direct costs

Source: Authors' compilation based on Cavallo & Noy (2009) and various DaLA reports.

assessments appear to capture high-level effects. Third, DaLAs incorporate numerous assumptions that are appropriate for short-term damage and loss estimates, and that can be revised by the affected government once more detailed assessments are performed. Table 4 presents a summary value of direct and indirect costs for Hurricanes Joaquin, Matthew, Irma, and Dorian.

Table 4.

Total Direct and Indirect Costs per Hurricane

	Joaquin (2015)		Matthew (2016)		Irma (2017)		Dorian (2019)	
	Millions of U.S. Dollars	Percent of GDP	Millions of U.S. Dollars	Percent of GDP	Millions of U.S. Dollars	Percent of GDP	Millions of U.S. Dollars	Percent of GDP
Direct costs	104.8	0.9	373.9	3.1	32.3	0.3	2,454.2	18.1
Indirect costs	9.7	0.1	145.5	1.2	86.9	0.7	718.0	5.3

Sources: ECLAC (2016, 2017, 2020a, 2020b); and International Monetary Fund, October 2020 *World Economic Outlook*.

Hurricane Joaquin

Based on the 2015 DaLA, Hurricane Joaquin caused US$104.8 million in direct costs, mostly to roads, telecommunications and housing.[21] The greatest direct costs were incurred on Long Island (34 percent of direct costs, US$35.7million), Acklins (25 percent of direct costs, US$26.5 million), and San Salvador (19 percent of firect costs, US$19.6 million). Damage to infrastructure was the most prevalent, accounting for 53 percent of all direct costs. Within infrastructure, roads were the most affected subsector due to remote locations and weak pre-existing conditions. The telecommunications subsector was the second most affected sector, with direct damage reaching 20 percent of the network, valued at US$20.7 million. In Rum Cay, the hurricane interrupted the provision of electricity and telecommunications, and the docks were also affected, which hindered relief efforts. Social sectors were the next most affected sector, accounting for 36 percent of all direct costs (US$37.9 million), with the vast majority of that damage to housing infrastructure. The productive sector incurred 11 percent of direct costs (US$11.2 million), predominantly in the tourism subsector.[22] Most direct costs related to telecommunications were due to fallen lines and utility poles. Rum Cay suffered an island-wide loss of both mobile and wired services and damage to fibre and copper cables and utility poles.

Joaquin generated US$9.7 million in indirect costs, mostly in the tourism and social sectors. Indirect costs were mostly caused in San Salvador (48 percent of indirect costs, US$4.6 million) and Long Island (37 percent, US$3.5 million). Rum Cay was the smallest island in size and population affected and therefore incurred the lowest cost (34 percent, US$4.4 million). Its productive sector, however, incurred the highest indirect costs (51 percent, US$4.9 million). This was exacerbated by road = damage, which indirectly affected tourism services and, through that impact, employment. The next most affected sector in terms of indirect costs was the social sector (28 percent of total indirect costs US$2.7 million), while the infrastructure sector accounted for 14 percent of indirect costs (US$1.3 million).

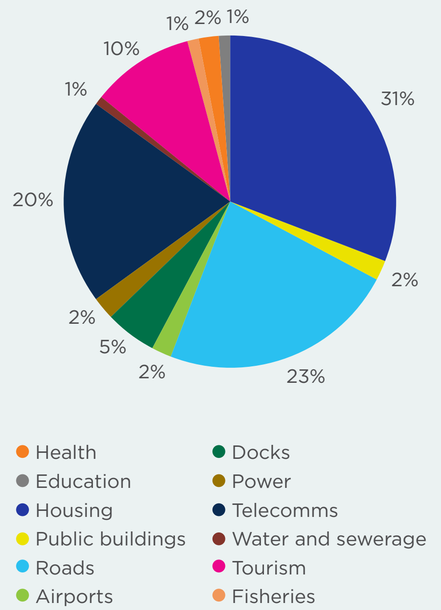
The total population affected by Joaquin reached 5,028, of which 61.5 percent were on Long Island, 18.7 percent on San Salvador, and 11.24 percent on Acklins. Northern dwellings on Acklins were the most severely affected by the storm. The most inhabited dwellings on the east side of Crooked Island were the most severely affected, which showed how widespread the effect of the hurricane was on the island's population. The entire population was impacted by the interruption of water services. The south was the most damaged part of the island. The entire population of Rum Cay Island was affected due to electricity and telecommunications disruptions. San Salvador also recorded damage to dwellings across the whole island. A large number of persons were temporarily relocated to New Providence, exacerbating pre-hurricane depopulation trends that had been taking place prior to the disaster.

21. Due to logistics, the DaLA team was unable to meet with the authorities in Rum Cay. Information for this island was compiled with data from the government of The Bahamas.
22. The only affected islands with a port of entry were Long Island and San Salvador. With the exception of Club Med in San Salvador, the hotels on the affected islands were small-scale establishments, most of which did not have insurance or financing mechanisms to respond to the damage, which likely delayed reconstruction. Club Med was the largest private sector asset to be directly impacted by Hurricane Joaquin.

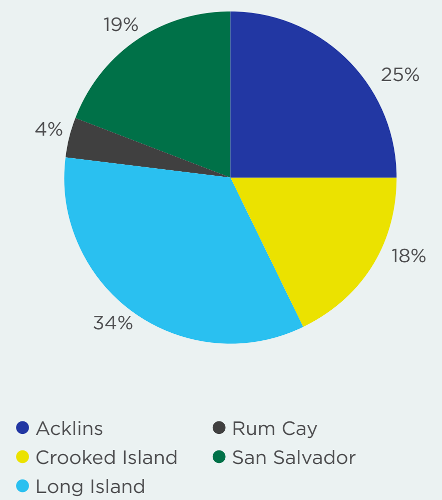
Figure 7.

Total Direct and Indirect Costs to The Bahamas from Hurricane Joaquin by Sector and Island

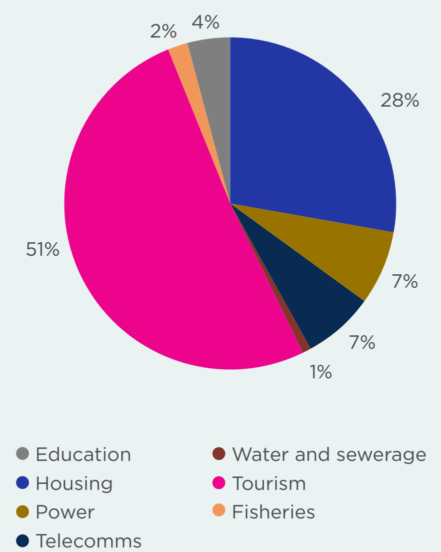
a. Total Direct Costs by Sector



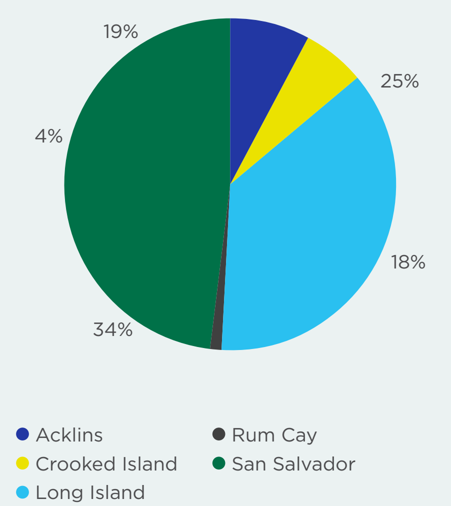
b. Total Direct Costs by Island



c. Total Indirect Costs by Sector



d. Total Indirect Costs by Island



Note: Categories with 0% have been omitted from the labels.
Source: ECLAC (2016).

Hurricane Matthew

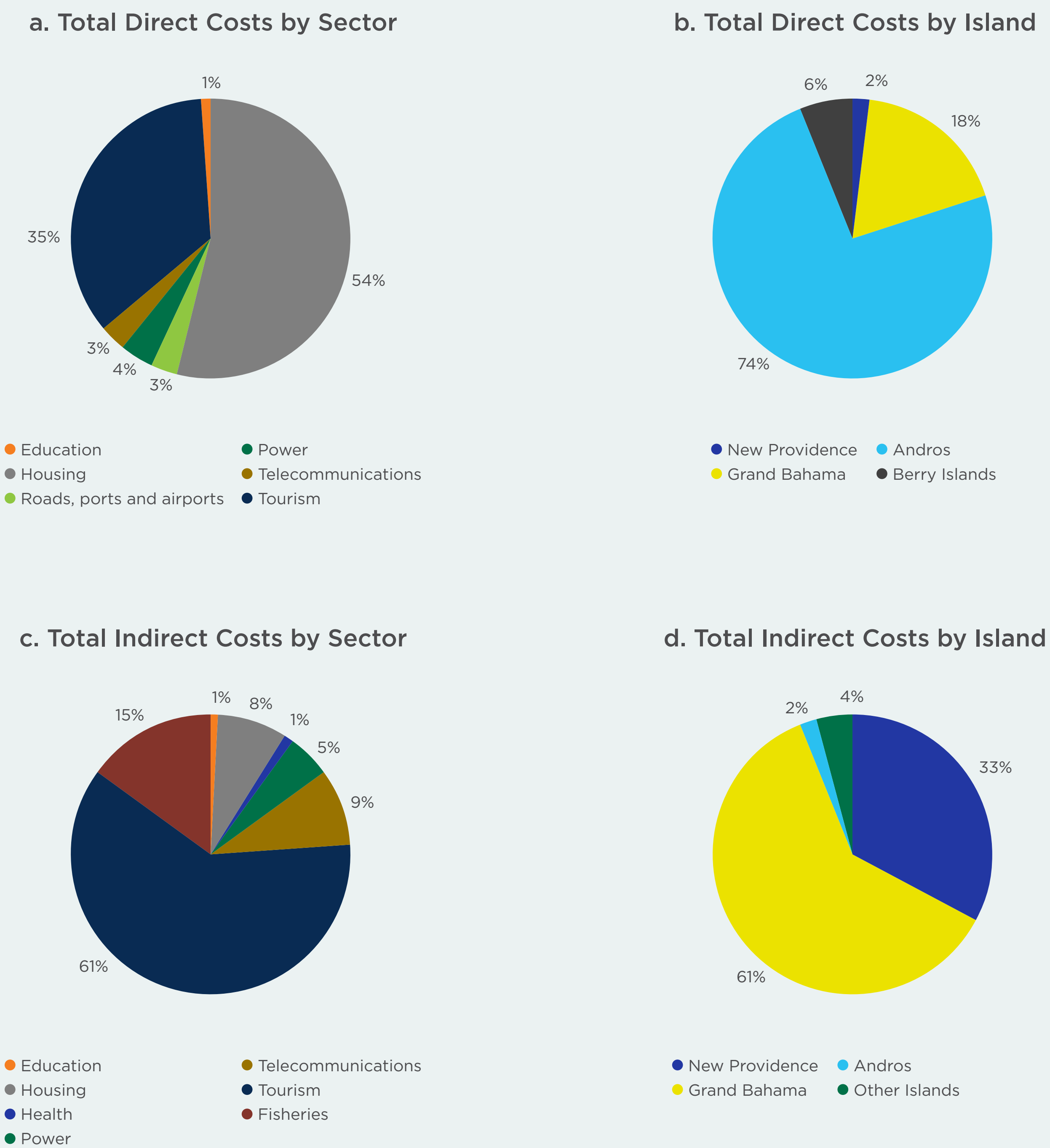
Total direct costs to The Bahamas as a result of Hurricane Matthew reached US$373.9 million. Of the total direct costs, 54.5 percent was in the social sector, 10.2 percent in infrastructure, 34.8 percent in productive sectors, and 0.5 percent in environment sectors. Housing was severely affected by Hurricane Matthew, reaching US$200.1 million (53.5 percent) in direct costs on New Providence, Grand Bahama, Andros, and the Berry Islands. Many costs to infrastructure were due to non-compliance with structural criteria (inadequate reinforcement or the concrete mix used). Direct costs in the telecommunications sectors were estimated at US$9.9 million (2.6 percent), while direct costs to the energy sector were estimated at US$16.4 million (4.3 percent), mostly as a result of high winds. Grand Bahama was the most affected by power outages, which continued over five weeks after the event. Direct costs to the water and sanitation sector reached US$1.2 million (0.3 percent). Total direct costs to the tourism sector were US$129 million (34.5 percent). With regards to the environment, the most damaged natural resource was native hardwoods and other non-pine tree species on New Providence, Grand Bahama, and Andros.

Indirect costs reached US$140.5 million, mostly in tourism: 75.1 percent of indirect costs were in the productive sectors, 14.9 percent in infrastructure, 9.9 percent in social sectors, and 0.1 percent in environment sectors. Within productive sectors, 80.7 percent of indirect costs were tourism-related, while for infrastructure most indirect costs (62.9 percent) were in telecommunications. The telecommunications sector experienced widespread outages (more so than from Hurricane Joaquin), which led to indirect costs of US$13.6 million (9.6 percent). Grand Bahama and New Providence had the longest outages. Electricity outages had effects on the supply of water and sanitation. Total indirect costs in the tourism sector reached US$88.3 million (62.8 percent), mostly incurred on Grand Bahama.

The impact on the population was moderate. No deaths or injuries were reported during the event, but 3,221 people were sheltered in 50 facilities throughout the four affected islands analysed in the DaLA.

Figure 8.

Direct and Indirect Costs to The Bahamas from Hurricane Matthew by Sector and Island



Note: Categories with 0% have been omitted from the labels.
Source: ECLAC (2020a).

Hurricane Irma

Total direct costs to The Bahamas from Hurricane Irma were estimated at US$32.3 million, mostly in water and sanitation and housing. Direct costs related to social sectors reached US$16.8 million (52 percent), most of which were in the housing sector. The health sector incurred mild damage (2 percent of total direct costs). Hospitals in Freeport and Nassau reported damage. Direct costs in the infrastructure sector reached US$13.7 million (42.4 percent), of which US$10.3 million (31.9 percent) was in the transportation sector. Excluding the Ragged Island airport, the greatest losses to transport infrastructure were on Inagua. Roads, and particularly those near the coast, were affected by the sea surge, and the airport on Ragged Island suffered damage to the terminal and runway. The ports in Bimini had considerable damage due to the sea surge and tidal effects. Direct costs to telecommunications, power, and water and sanitation were US$2.1 million (6.5 percent), US$800,000 (2.4 percent), and US$500,000 (1.5 percent), respectively. Ragged Island suffered the greatest costs to its telecommunications infrastructure (accounting for 69 percent of total telecommunications damages),[23] followed by Grand Bahama and Inagua (both of which had tornado damage), Bimini, and Andros. Damages in the power sector were limited, partly due to prior preparation before Irma reached The Bahamas. However, the arrival of Hurricane Maria a few months later impeded reconstruction in the power sector on some islands such as Mayaguana. Direct costs in the water and sanitation sector (US$500,000) were also limited, with the exception of Ragged Island and Bimini, which suffered damage. Ragged Island's desalination plant and the Bimini underwater line were both damaged. In relative terms, productive sectors incurred a much smaller share of direct costs at US$1.7 million, most of which was in the tourism sector (US$600,000) and fisheries sector (US$1.1 million).[24] Tourism did not incur large direct costs, but it was affected by disrupted visitor inflows in the aftermath of the storm. Ragged island suffered the largest share of direct costs in the tourism sector (US$400,000), followed by Bimini (US$700,000). In the fisheries sector, the fishing port of Duncan Town on Ragged Island and a ramp in Matthew Town on Inagua were damaged.[25] New Providence incurred the greatest direct costs (US$500,000).

Indirect costs were estimated at US$86.9 million, mostly in tourism. In the social sector, indirect costs reached US$2.4 million (2.8 percent), of which US$1.5 million (1.7 percent) was in the education sector, US$500,000 (0.6 percent) in the health sector, and US$400,000 (0.5 percent) in housing. Indirect costs in infrastructure reached US$3.7 million (4.2 percent), of which most was in the transportation sector (US$2.2 million, 2.5 percent). Low indirect costs in telecommunications were due to the fact that most of the damage was in lesser-populated areas, and outages that affected larger groups of people were quickly fixed. Tourism suffered the bulk of indirect costs (78 percent, or US$68 million), mostly due to travel disruptions in the aftermath of the event. Indirect costs in the fisheries sector amounted to US$12.9 million (15 percent), mostly concentrated in New Providence and Spanish Wells. Disruptions in fisheries were more severe, particularly as the lobster fishing season ranges from August to March, with the most productive months being August and September.

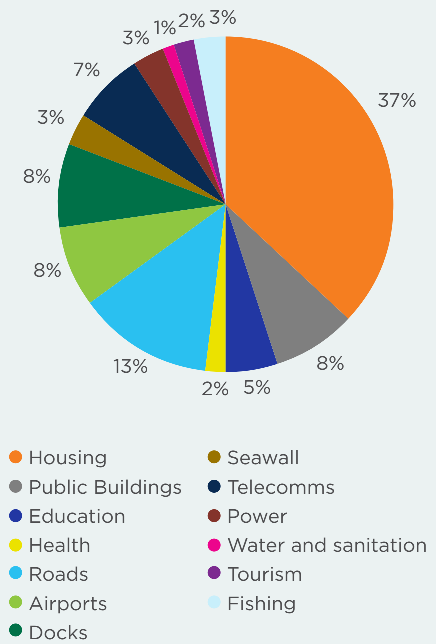
Approximately 54,906 persons were affected by Hurricane Irma (16 percent of the population). Inagua was the only island that had been experiencing a population decrease prior to the hurricane, whereas Grand Bahama had been experiencing a population increase. Approximately 892 people were evacuated from three of the five islands, including 365 from Bimini, 487 from Inagua, and 40 from Ragged Island.[26]

23. The direct costs to telecommunications include those reported by BTC and Cable Bahamas, as well as estimates on damage that was not reported. Figures for ALIV are not included, as the company reported no significant damage.
24. In the fisheries sector, only direct costs related to commercial fishing vessels, fishing gear, and other equip-ment to prepare or preserve the catch were considered.
25. Damage to the port of Duncan Town is accounted for in the infrastructure sector and damage for sports fishing is accounted for in the tourism sector.
26. An emergency evacuation plan from the most threatened islands was executed prior to the arrival of Irma. Persons were taken from Mayaguana, Inagua, Crooked Island, Acklins, Long Cay, and Ragged Island to Nassau.

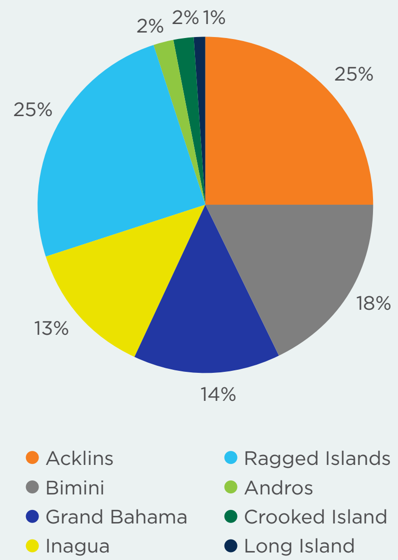
Figure 9.

Direct and Indirect Costs to The Bahamas from Hurricane Irma by Sector and Island

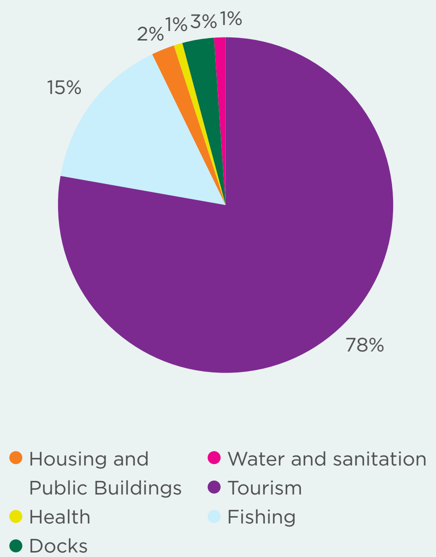
a. Total Direct Costs by Sector



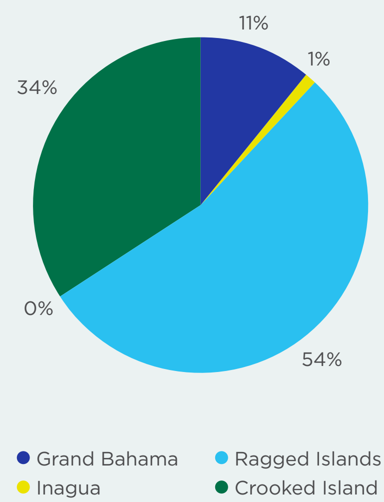
b. Total Direct Costs by Island



c. Total Indirect Costs by Sector



d. Total Indirect Costs by Island



Note: Categories with 0% have been omitted from the labels.
Source: ECLAC (2017).

Hurricane Dorian

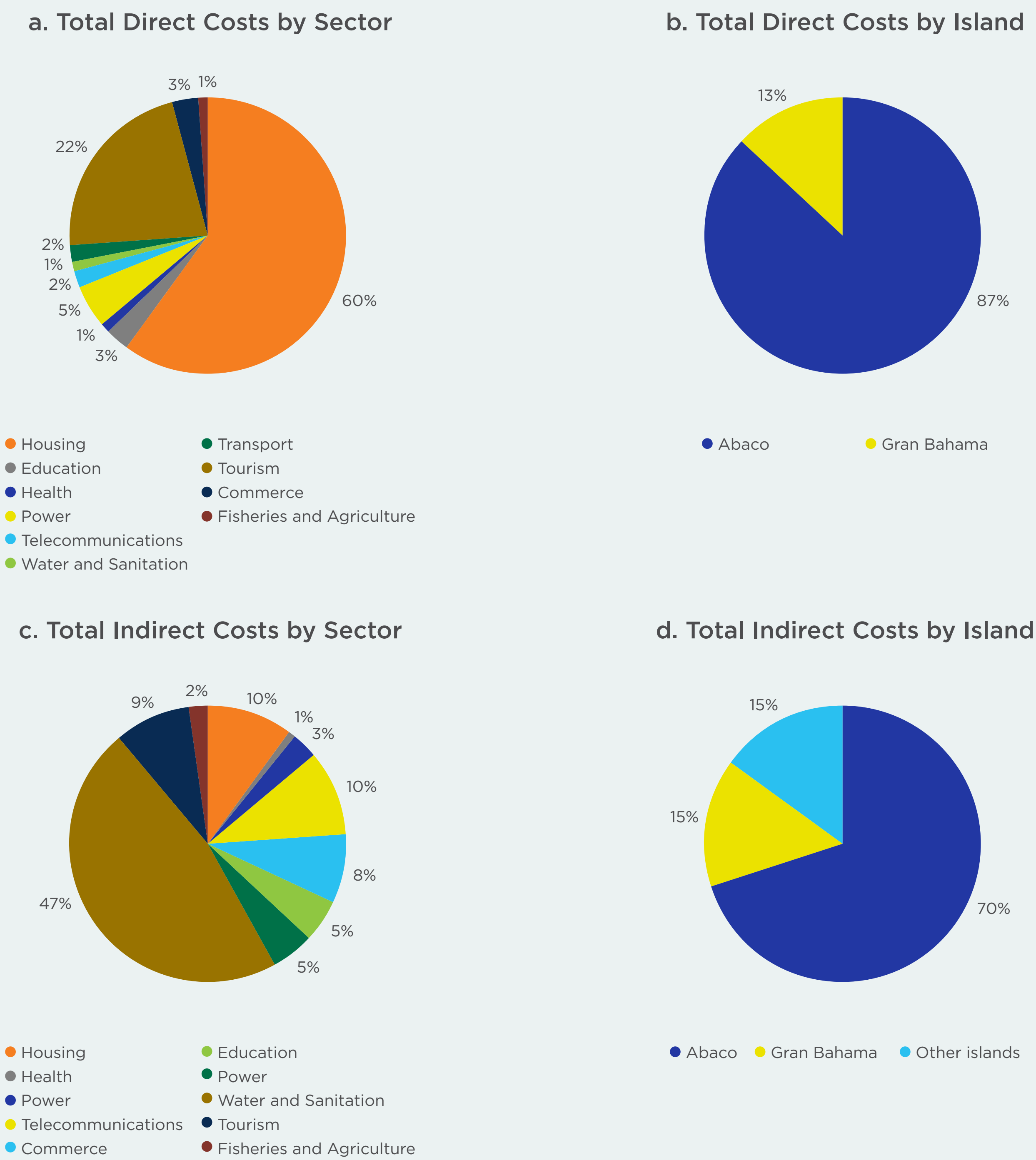
Total direct costs to The Bahamas from Hurricane Dorian reached US$2.5 billion, with housing and tourism particularly hard hit. Abaco suffered 87 percent of the direct costs and Grand Bahama 13 percent. Direct costs to the social sector reached US$1.6 billion (64 percent), with most of that in Abaco. Within the social sector damage, almost 93 percent was in the housing subsector. Approximately 9,000 homes had direct damage, with more than 75 percent of homes in Abaco directly damaged. Direct costs to the productive sector reached US$620.9 million (24 percent), of which US$529.6 (21.2 percent) was in the tourism sector. Direct costs to infrastructure reached US$239.1 million (9.5 percent), of which 54.1 percent was in the power sector. The airports suffered high operational damage due to flooding and roof failure due to high-speed winds, and seaports were impacted by waves, storm surge, and wind. The transport sector incurred US$50.8 million (2 percent) in direct costs, with 53 percent of the damage on Grand Bahama, almost all of it sustained at the Grand Bahama International Airport.

Total indirect costs reached US$717.3 million, mostly in tourism. Of the total, 70 percent was in Abaco, 15 percent in Grand Bahama, and 15 percent in other islands. Indirect costs in the social sector reached US$93.2 million (13 percent), of which US$65 million (2.6 percent) was in the housing sector. Indirect costs in the environmental sector reached US$27.5 million (3.8 percent). Wave action, storm surge, and high winds produced partial to severe destruction of mangroves, coral reefs, seagrass beds, and forests on both Abaco and Grand Bahama. As a result, ecosystems were left in a critical state and pre-existing vulnerabilities were exacerbated, with an expected decrease in ecosystem services provision in the short and medium term. Indirect costs in the productive sector were approximately US$400.3 million (55.8 percent), of which 83.8 percent were in Abaco. **Of the total amount, 81.2 percent was in the tourism sector.** Hurricane Dorian impacted two major tourist destinations of The Bahamas and disrupted the tourist flows for several days before and after the storm in the rest of the Lucayan Archipelago. Indirect costs in the infrastructure sector reached US$197.1 million (27.5 percent), 35 percent of which was in the power sector, followed by telecommunications. Disruption of power services was particularly notable on Abaco.

Most inhabitants of both islands were affected by the hurricane, either directly or indirectly. The total affected population reached approximately 29,472 persons (40 percent of the total combined population of Abaco and Grand Bahama). As of October 18, 2019, there were 67 confirmed deaths and 282 missing persons.

Figure 10.

Direct and Indirect Costs to The Bahamas from Hurricane Dorian by Sector and Island



Note: Categories with 0% have been omitted from the labels.
Source: ECLAC (2020b).

Summary

The results presented in this section reinforce previous results but also raise certain additional points. Some interesting patterns appear when comparing Tables 2 and 4.

1. **Low direct and indirect costs could be related to a smaller economic effect of natural disasters.** Hurricane Irma incurred significantly lower direct and indirect costs than the other hurricanes. Table 2 in fact showed that the country registered no economic effects in either the month, quarter, or year of the event. However, the results do not show that the greater the direct and indirect costs, the greater the economic effect. Hurricane Dorian resulted in the largest costs by far but did not have the greatest economic effect.

2. **There does indeed seem to be a relation between what islands are affected and the severity of the economic contraction.** Hurricane Matthew had the most severe economic effects in the month of the event (4.4 percent contraction), and although it imposed lower overall costs than Hurricane Dorian, both New Providence and Grand Bahama (the largest islands economically) had the highest costs.

3. **Neither the magnitude nor the composition of costs seems to impact the economic effects of the disasters on the Family Islands.** The Family Islands were most recurrently hit by these natural disasters, yet they did not record contractions, as shown in Table 2. This could be due to aggregation of the results, correlations between islands, or the small size of these islands' economies, which could contribute to a quick recovery.

4. **Finally, the breakdown of the costs by sector is very similar in all the events covered, irrespective of their magnitude.** For example, irrespective of the volume of costs, the most direct costs from all four disasters were in housing, transport, and tourism, and most of the indirect costs were in tourism. Yet, different economic effect results in Table 2 would suggest that the composition of the sectors does not matter as much as the island that incurs the costs. These results therefore signal that there would be substantial benefits from ensuring climate-resilient investments and insurance mechanisms in these three sectors. These results should, however, be taken with care, considering the DaLa methodology and purpose.

4. Conclusion

The Bahamas is extremely vulnerable to the effects of natural disasters and climate change. The country has been hit by 25 hurricanes in the last 25 years that have resulted in substantial human and economic losses. Natural disasters are expected to increase in frequency and intensity going forward as a result of the effects of climate change. Therefore, better understanding the effects of these events on the economy of the country, and promoting measures and reforms to mitigate their effects, is becoming more urgent than ever.

This paper has analysed the economic effect of four of the most recent major hurricanes to impact The Bahamas in the past decade. Making use of historical night light intensity between 2015 and 2019, a monthly GDP time series by island prior to and immediately after Hurricanes Joaquin (2015), Mathew (2016), Irma (2017), and Dorian (2019) was reconstructed utilizing an economic activity index. These estimates were created using a new methodology that enabled monthly GDP by island to be estimated through the level of luminosity on the surface of The Bahamas. Using these results, the paper analysed the effects of the four hurricanes by comparing the spatial variation of satellite night lights as an indicator of the country's economic activity before and after each hurricane. Satellite night lights observed from space are publicly available and have been used before to measure economic activity. Moreover, this methodology could be replicated in the future to measure the effectiveness of the actions being taken to help the recovery of the Bahamian economy. The analysis was supplemented by an examination of the direct and indirect costs to The Bahamas from the four hurricanes as determined by Damages and Losses Assessments (DaLAs) conducted by the Economic Commission on Latin America and the Caribbean and the Inter-American Development Bank.

The results of this study suggest that the macroeconomic effect of these events and the recovery times following them are highly dependent on which islands are impacted.

First, the results show that The Bahamas experiences a decrease in the year-to-year nominal growth rate during the month and quarter of a hurricane impact event but does not show a contraction of GDP in the year of the event. However, this does not mean that the damages are insignificant. On the contrary, the total damage from these four hurricanes was nearly US$4.4 billion, which is equivalent to about 30 to 40 percent of Bahamian GDP. Additionally, the amount of damage may increase in the future due to the effects of climate change. Therefore, disaster risk reduction and climate change resilience/adaptation should continue to be a priority in public policy for the country's macroeconomic and socioeconomic sustainability.

Second, New Providence and Grand Bahama experienced larger GDP contractions following the hurricanes, but no such clear pattern could be obtained for the Family Islands (for either annual or monthly data). This could be due to a reorganization of tourism flows during the year across those islands, or to a high degree of correlation between them, which would average out any large contractions in a small number of Family Islands.

Third, the economic recovery times to achieve pre-hurricane GDP levels took between four and eight months on average for the hurricanes studied.

Finally, the composition of sectors affected by the four hurricanes did not seem to have had a major effect on the severity of the economic shock. Indeed, the analysis found that for all of the hurricanes, tourism, transport infrastructure, and housing were recurrently the most affected sectors. This calls for their possible prioritization in climate change adaptation and disaster risk management efforts.

4.1. Limitations of the Study

Despite the innovative methodological approach and the use of new sources of information on these events, there are shortfalls in this study that should be considered.

First, the methodology presented is tailored to the availability of information in the country. In this regard, the study uses the results of household surveys and population censuses to estimate the distribution of GDP and population per island. The caveats of the results are, therefore, linked to the assumptions made to estimate the base year of GDP per island and the trajectory of population per island.

Another caveat of the methodology is that the night light data used (Day Night Band of the VIIRS instrument of the Suomi-NPP satellite) are sensitive to infrared and almost blind to blue, which makes LEDs produce less signal than other types of lighting (typically 50 percent less). Since there currently is a technological transition from sodium lamps to LEDs, that could affect the brightness of the maps, and therefore, the results. This is an important caveat particularly in places where there is a significant transition of sodium light bulbs (old technology) to LEDs (new technology) (see Annex 1).

With respect to the DaLAs, they offer systematic and comparable damage and loss estimates that provide a snapshot of the situation immediately after the event to inform strategic decision-making related to the response and recovery. The study analysis and results would benefit from forensic analysis of government accounts, sector-specific and island-specific economic analysis/studies, microeconomic and livelihood studies, population movement studies, and documentation of government and private sector response and recovery interventions. Such information could help identify the causes of and reasons behind specific trends that this study has identified, which in turn could inform policies, strategies, and plans to manage post-disaster economic impacts in The Bahamas and subsequent recovery.

4.2. Recommendations

Several key recommendations stem from the results presented in this paper. The innovative methodological approaches and data sources used allow for the assessment of the effect of recent hurricanes by island. Future studies should consider conducting further analysis using the satellite luminosity method to better understand economic recovery patterns and identify zones of high GDP concentration and economic importance. These could then be prioritized in risk assessments, risk mitigation measures, and resilience plans. Greater disaggregation of data by Family Islands would also allow for more detailed results and possibly clearer conclusions for these territories. It would also provide greater insights into the drivers of growth and economic contractions on small island states more broadly. The satellite night light methodology could even be used as a tool to assess GDP effects immediately after a disaster and to track economic activities post-disaster, complementing DaLA assessments. In addition, the methodology could be used to monitor the GDP recovery time of specific islands (macroeconomic recovery).

These results should also be used to inform disaster risk management and reduction plans in The Bahamas. The Global Framework on Disaster Risk Reduction provides a roadmap toward this end. It proposes five cross-cutting pillars of action that can be applied to every sector – risk identification, risk reduction, preparedness, financial protection, and resilient recovery. Taken together, these pillars provide a framework that can apply not only to the recurring threat of hurricanes, but to the country's long-term imperative to mitigate and adapt to the effects of climate change and sea-level rise. It is hoped that the methodology developed and the results presented will increase technical and scientific understanding of the economic effects of hurricanes in The Bahamas and serve as an additional resource to inform government stakeholders involved in disaster risk management, finance, insurance, and recovery.

Annex 1. Data and Methodology

Data

This paper uses four sources of information to estimate the GDP by island in The Bahamas:

1. Night time light data captured by satellite sensors
2. GDP data based on national accounts
3. Population density
4. Household income

The night time light data were obtained from the National Geophysical Data Center (NGDC) of the U.S. National Oceanic and Atmospheric Administration (NOAA). The national GDP data were obtained from the International Monetary Fund (IMF). Population density was estimated using population censuses of The Bahamas. Household income comes from the Department of Statistics of The Bahamas (DSoB).

Night Time Light Data

The night time light data can be divided in two periods: (1) 1992–2013 and (2) 2013–2020. The data in the first block have an annual frequency, while the data in the second block have a monthly frequency.

Data for the period 1992–2013 were collected by the Defense Meteorological Satellite Program Operational Lines-can System (DMSP-OLS) and were maintained and processed by the NGDC. The images are processed to remove cloud cover and short-lived lights (such as wildfires) to produce the final product. Each pixel (0.008241 degrees equivalent to 0.9174 square kilometres[27]) in the luminosity data is assigned a digital number that represents its luminosity. Digital number are integers ranging from 0 to 63.

Data corresponding to the period 2013–2020 are generated by the Earth Observations Group at NOAA's National Centers for Environmental Information. These data are obtained using Day/Night Band data from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on the Suomi-NPP satellite. Each pixel (0.000007 degrees equivalent to 0.000779 square kilometres) in the luminosity data is assigned a digital number representing its luminosity. However, the digital number of VIIRS has great variability and takes positive and negative values with decimals, unlike the digital number of the DMSP, which only takes positive integers from 0 to 63.

In line with Seminario and Palomino (2021), the luminosity variable corresponds to the average of the digital number of the pixels that make up the geographic region of analysis. However, we use different procedures because the DMSP data are annual, while the VIIRS data are monthly.

We calculate the annual luminosity level for the period 1993–2013 using the following formula:

$$LA_{i,t} = \frac{\sum_{j=1}^{N_{i,t}} DN_{j,i,t}}{N_{i,t}},$$

27. We consider that an arc of a degree is equal to 111.32 kilometers.

Where $LA_{i,t}$ corresponds to the level of luminosity of region i in year t, $DN_{j,i,t}$ represents the digital number of pixel j of region i in year t, $N_{i,t}$ corresponds to the total number of pixels that region i has in year t.

We calculate the annual luminosity level for the 2013–2020 period using the following formula:

$$LB_{i,t} = \frac{\sum_{m=1}^{12} LM_{i,m,t}}{12},$$

where $LA_{i,t}$ corresponds to the level of luminosity of region i in year t; $LM_{i,m,t}$ *corresponds to the levels of luminosity of region* i *in month* m *of year* t *and is estimated using the following formula:*

$$LM_{i,m,t} = \frac{\sum_{j=1}^{N_{i,t}} DN_{j,i,m,t}}{N_{i,m,t}},$$

where $DN_{j,i,m,t}$ represents the digital number of pixel j of region i in month m of year t, Ni,m,t corresponds to the total number of pixels that region i has in month m of year t.

Finally, we fit the VIIRS data to the DMSP data using the following formula:

$$L_{i,t} = LA_{i,t_0} * \frac{LBC_{i,t}}{LBC_{i,t_0}},$$

where $L_{i,t}$ corresponds to the final level of luminosity of region i in year t, $LA_{i,t0}$ represents the luminosity level of region i in year t_0, which corresponds to the year that the DMSP and VIIRS databases are available (i.e., 2013), $LBC=(LB+\theta)>0$ corresponds to the luminosity level of the VIIRS adjusted to the luminosity level of the DMSP for the period 2013–2020, and θ is a constant positive value necessary to eliminate the negative values of the luminosity level calculated with the satellite images from the VIIRS.[28]

National Accounts Data

The IMF has presented annual GDP series for the Bahamas since 1980, and the DSoB has been making efforts to generate GDP series with greater temporal and spatial disaggregation. The DSoB has generated quarterly series of GDP at the national level since the first quarter of 2015. It has also generated annual series of GDP for three administrative divisions since 2015: (1) New Providence, (2) Grand Bahama, and (3) the Family Islands. However, due to the short time horizon of the quarterly and subnational series, we will only use the annual GDP series for the period 1992–2020.

Population Census Data

Based on the population censuses of 1980, 1990, 2000, and 2010, we have generated population series for each of the regions analysed for the period 1992–2020. Census data have been obtained from the DSoB. In line with Zegarra *et al.* (2020) and Seminario and Palomino (2021), the population series have been generated using the Piecewise Cubic Hermite Interpolating Polynomial (PCHIP) function implemented in Matlab. Also, using information from ArcGIS, we have calculated the land area in square kilometres of each of the islands analysed. Combining the population series and the territorial extension, we have generated series of population density at the island level for the period 1992–2020.

Methodology

We describe the methodology for estimating GDP with greater spatial and temporal disaggregation in four subsections. In the first subsection, we describe the method of Geary and Stark (2002). In the second stage we describe the method used to generate the income series for all the islands in the base year 2013. In the third subsection we describe the stages used by Seminario and Palomino (2021) to estimate the GDP of each of the islands. In the fourth subsection we describe the method used to put the annual GDP series in monthly terms.

28. In line with Seminario and Palomino (2021), we consider θ equal to 10 to correct the negative values of the VIIRS brightness level for the period 2013–2020.

Geary-Stark Method

Geary and Stark (2002) developed a method that allowed for the distribution of GDP of the United Kingdom to be distributed for analytical purposes among its main regions: Scotland, Wales, England, and Ireland. The method requires knowing the employment and wages of the different regions. It is assumed that the ratio between GDP per capita and a region and the national average is proportional to that between regional wages and national average wages. Subsequently, various authors have used the method proposed by Geary and Stark to derive GDP statistics at the subregional level in different countries (Badia-Miró 2015; Crafts 2004).

However, it is not always possible to have the information required by the Geary and Stark method. Therefore, Seminario, Zegarra, and Palomino (2019) considered it necessary to adapt the Geary and Stark method to derive GDP series consistent with stylized facts at the Peruvian department level for the period 1795–2018. This modified method was also used by Seminario and Palomino (2021) to derive GDP series at the level of provinces and districts of Peru for the period 1993–2018.

Therefore, in line with Seminario and Palomino (2021), we use the modified Geary and Stark method to (1) generate GDP series at the island level for the base year 2013, and (2) adjust the GDP series to national level to island-level GDP series.

Household Income Estimates

The estimation of income for islands that do not have information consists of four stages: (1) generating income series for the islands using household surveys, (2) generating series of luminosity and population density for all islands, (3) estimating the parameters of a production function for islands that have income information, and (4) estimating income for islands that do not have income information.

In line with Seminario and Palomino (2021), we estimate the following production function for the islands that have income information in the 2013 household survey:

$$\ln(y_i) = \alpha_0 + \alpha_1 \ln(L_i) + \alpha_2 ln(L_i)^2 + \alpha_3 ln(L_i)^3 + \alpha_4 \ln(D_i) + \mu_i,$$

where y_i represents the income of island i, L_i corresponds to the average luminosity level of island i, and D_i represents the population density of island i.

Using the coefficients estimated in the previous step, we estimate the income of the islands that do not have income information in the household survey using the following formula:

$$\ln(\hat{y}_j) = \hat{\alpha}_0 + \hat{\alpha}_1 \ln(L_j) + \hat{\alpha}_2 ln(L_j)^2 + \hat{\alpha}_3 ln(L_j)^3 + \hat{\alpha}_4 \ln(D_j),$$

where $\ln(\hat{y}_j)$, L_j, and D_j correspond to the estimated income in logarithmic terms, average level of luminosity, and population density of island j, respectively.

Estimation of GDP

In line with Zegarra *et al.* (2020) and Seminario and Palomino (2021), the estimation of the GDP of small territorial regions consists of five stages: (1) generating series of luminosity and population density, (2) estimating the GDP of a base year, (3) estimating the parameters of a production function, (4) generating GDP series for the entire period of analysis, and (5) adjusting the estimated series of the islands' GDP to the national GDP.

We generate the GDP for the base year 2013 of each island in two stages using the method adapted from Geary and Stark and the information on household income: (1) distribution of GDP according to estimated income levels for two groups of islands (with and without survey data), and (2) distribution of GDP within each island group according to their income levels. **To distribute the GDP of each island according to its income level, we use the following formula:**

$$y_{i,k,t_0} = y_{k,t_0} * \frac{I_{i,k,t_0}}{\sum_j^N I_{j,k,t_0}},$$

where $y_{i,k}$ corresponds to the estimated GDP with the data on income of island i that belongs to group k (with and without census data), y_k represents the GDP of group k, $I_{i,k}$ corresponds to the income of island i of group k, $\sum_j^N I_{j,k}$ represents the total income of the islands of group k, N corresponds to the total quantity of the islands of group k, and t_o corresponds to the base year 2013.

We estimate the parameters of the cubic production function for each island using the series of luminosity and population density with the following econometric specification:

$$\ln\left(\frac{y_{i,t_0}}{a_i}\right) = \alpha_0 + \alpha_1 \ln(L_{i,t_0}) + \alpha_2 ln(L_{i,t_0})^2 + \alpha_3 ln(L_{i,t_0})^3 + \alpha_4 \ln(D_{i,t_0}) + \mu_{i,t_0},$$

where y_i represents the GDP of island i, a_i represents the area in km² of island i, L_i corresponds to the average level of luminosity of island i, D_i represents the population density of island i, and t_0 corresponds to the base year 2013.

Using the coefficients estimated in the previous step, we estimate the GDP of each island in logarithmic terms using the following formula:

$$\ln\left(\frac{\hat{y}_{i,t}}{a_i}\right) = \hat{\alpha}_0 + \hat{\alpha}_1 \ln(L_{i,t}) + \hat{\alpha}_2 ln(L_{i,t})^2 + \hat{\alpha}_3 ln(L_{i,t})^3 + \hat{\alpha}_4 \ln(D_{i,t}),$$

where $\ln(\hat{y}_{i,t}/a_i)$, $L_{i,t}$, and $D_{i,t}$ correspond to the estimated GDP per km² in logarithmic terms, average light level, and population density of island i in period t, respectively. **We obtain the estimated GDP using the following equation:**

$$\hat{y}_{i,t} = a_i * e^{\left[\ln\left(\frac{\hat{y}_{i,t}}{a_i}\right)\right]}.$$

We obtained the GDP series in units of the base year using the following formula:

$$y_{i,t}^E = y_{i,t_0} * e^{[\ln(\hat{y}_{i,t}) - \ln(\hat{y}_{i,t_0})]}$$

where $y^E_{i,t}$ corresponds to the estimated GDP of island i in period t, $y_{i,t0}$ corresponds to the estimated GDP with the income data of island i in base year 2013, ln $(\hat{y}_{i,t})$ corresponds to the GDP estimated with data on luminosity and population density in logarithm terms of island i in period t, $\ln(\hat{y}_{i,t0})$ and corresponds to the GDP estimated with data on luminosity and population density in logarithm terms of island $_i$ in the base year.

Finally, using the modified version of the Geary and Stark method, we fit the islands' GDP data with national GDP data. **We adjust the estimated GDP series with satellite data for luminosity and population density using the following formula:**

$$y_{i,t}^F = y_t * \frac{y_{i,t}^E}{\sum_j^N y_{j,t}^E},$$

where $y^F_{i,t}$ corresponds to the final GDP of island i in period t, y_t represents national GDP in period t, $y^E_{i,t}$ corresponds to the estimated GDP of island i in period t, $\sum_j^N I_{j,t}$ represents total estimated GDP of all the islands in period t, and N corresponds to the quantity of all the islands.

Monthly Series

Time disaggregation plays a key role in the compilation of monthly or quarterly national accounts for many countries because it provides an objective way to combine the relevance of short-term indicators with the rigor and internal consistency of national accounts (IMF 2017; Quilis 2018).

However, temporal disaggregation is a complex process that competes with other techniques and problems regarding the use of limited resources. This competition gives priority to simplification and requires a broader perspective to integrate temporal aggregation with seasonal adjustment and chaining (Maravall 2006; Abad, Cuevas, and Quilis 2009).

According to Quilis (2018), Proietti's method is the most general and flexible, encompassing the Chow-Lin and Santos-Cardoso methods. However, the empirical application speaks in favour of much simpler methods, such as that of Denton (1971), especially for its robustness with respect to reviews.

Night light maps are published in a monthly series and can be transformed in monthly series that measure the variation of the average brightness in a region. Using the parameters used to estimate annual GDP, we can construct a monthly frequency index on economic activity. The application of the methodology on a monthly basis requires estimation of the population by island per month and the distribution of GDP for a given period. The population by month was estimated using the PCHIP and the population censuses. We assumed that the distribution of GDP in January 2013 reflected the annual distribution of GDP estimated for 2013 (base year of annual GDP). This methodology allows us to maximize the movements of the high-frequency indicator (brightness level) of each island for the period 2013–2020.

Annex 2. Luminosity Maps of Abaco, Grand Bahama, and New Providence

Figure A2.1.

Luminosity Maps – Abaco

Affected Region

September 2018

September 2019

May 2020

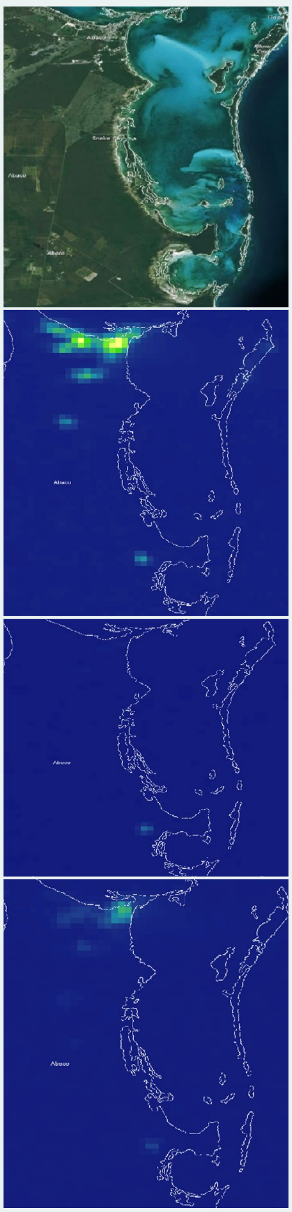


Figure A2.2.

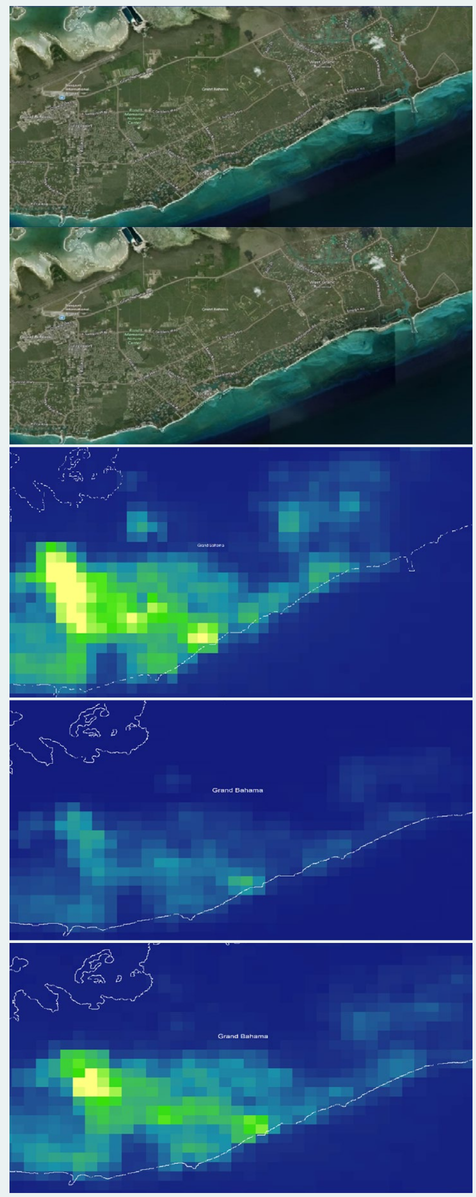
Luminosity Maps – Grand Bahama

Affected Region

September 2018

September 2019

May 2020



Note: September 2018, September 2019, and May 2020.
Sources: U.S. National Oceanic and Atmospheric Administration; and authors' calculations.

Figure A2.3.

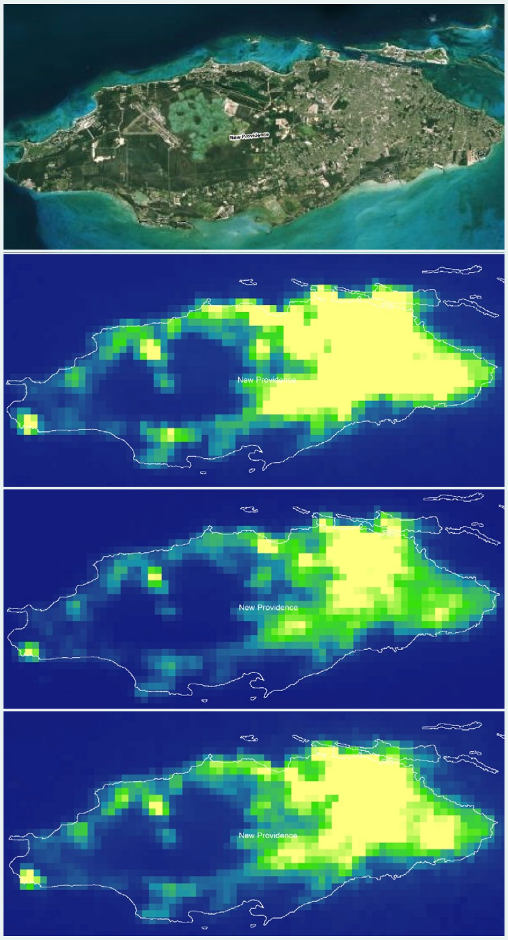
Luminosity Maps – New Providence

Affected Region

September 2018

September 2019

May 2020

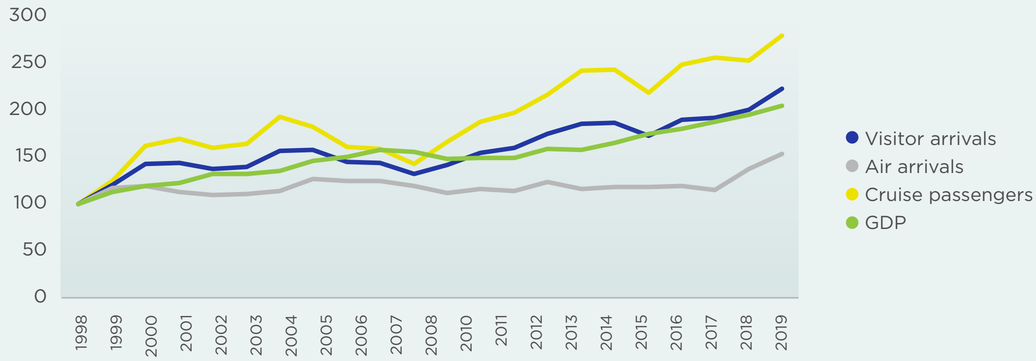


Note: September 2018, September 2019, and May 2020.
Sources: U.S. National Oceanic and Atmospheric Administration; and authors' calculations.

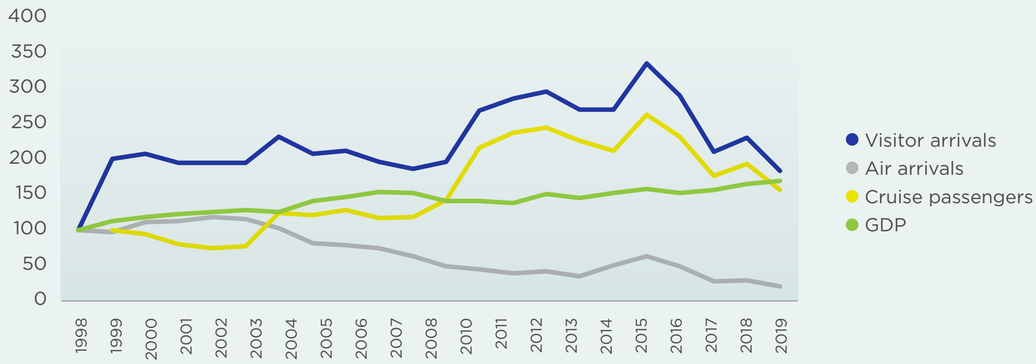
Annex 3. Index of Tourism Arrivals and Economic Activity by Island (1998 = 100)

Figure A3.1.

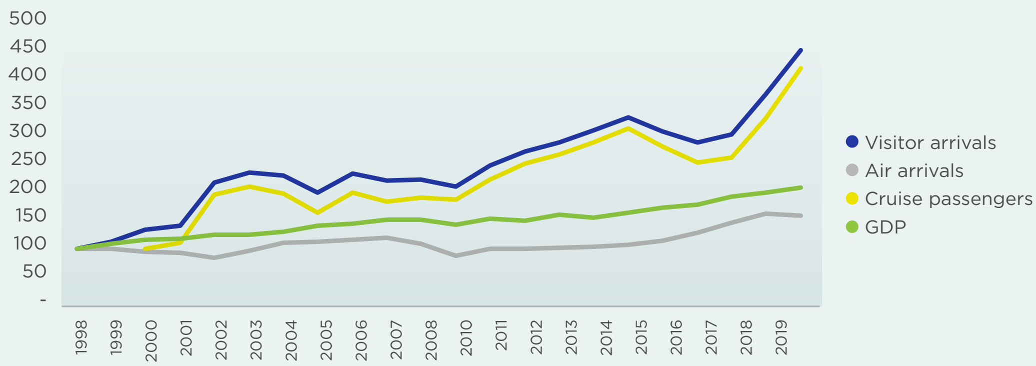
a. New Providence



b. Grand Bahama



c. Family Islands



Sources: Tourism Today Report (various reports); and authors' calculations.

Note: Due to data availability in the tourist arrivals database, the estimates on correlations for the Family Islands only include the following: Abaco, Andros, Berry Islands, Bimini, Eleuthera, Inagua, Long Islands, and San Salvador. The index on cruise passengers for the Family Islands starts in 2000 due to availability of information.

Annex 4. Indirect Cost Estimates

Health

The change in outpatient visits indicates the total number of outpatient visits that could not occur in the regular health facility after Hurricane Joaquin. This is based on the number of monthly outpatient visits and the period that health services were disrupted in that particular health facility. Given that public health does not have a market price, the losses were estimated using the remuneration to the factors. Since these are non-profit facilities, it is equal to the wages to the medical doctor and nurses.

Education

Indirect costs in this sector refer to the affected flows such as a reduction in output, measured in terms of the number of hours or days of classes taught.

Housing

Indirect costs relate to the interruption of accommodation services due to severe damage or destruction of the housing stock, making it temporarily or permanently uninhabitable. Estimates focus on the interruption of the service regardless of the type of tenure. Repairs and reconstruction are expected to last between 6 and 12 months.

Power

Indirect costs were calculated using historical data for electricity usage, the electricity tariff schedule for October 2015, and an estimate of the average time without electricity per customer, per island.

Telecommunications

Indirect costs were estimated based on the number of customers for each service and on average revenue per user of the various services.

Water and sanitation

Indirect costs in this sector are related to the interruption in the provision of water for human consumption and of sewerage and waste collection services. This is based on the percentage of the affected population and estimated consumption or use of these services per day.

Tourism

To estimate indirect costs, several assumptions were made related to high and low season dates, the rates in those seasons, the hotel occupancy rate, and the expected date of commencement of operations of the damaged hotels. An additional assumption about the number of fishing services that would be hired had to be made to reflect the typical activity of these lodges.

Fisheries

Indirect costs are estimated based on the reported number of affected fishermen and average monthly income.

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