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Population-Based Denominators Matter: Bias in U.S. Virgin Islands COVID-19 Vaccination Coverage Under Changing Population Counts

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Abstract

Purpose: The U.S. Virgin Islands (USVI) receives an updated population count once every 10 years and used 2010 decennial census population counts to estimate COVID-19 vaccination coverage during the COVID-19 emergency response. We investigated whether using outdated (2010) or modeled (2020 international database [IDB]) population counts biased vaccination coverage estimates used to inform public health priorities during the 2020–2022 COVID-19 response.

Methods: We estimated percentage of USVI residents with a completed primary COVID-19 vaccination series during December 16, 2020–September 20, 2022. Vaccination coverage was calculated as number of persons who completed the vaccination series divided by 2010 and 2020 decennial census population counts and 2020 IDB intercensal estimate.

Results: COVID-19 vaccination coverage using the 2020 population count was 12 percentage points higher than coverage using 2010 denominator (2010 denominator: 51%; 2020 denominator: 63%). Vaccination coverage estimated using 2020 IDB was approximately equal with the 2010 decennial census estimate (52%).

Conclusions: Using 2010 and modeled population counts underestimated 2020 USVI COVID-19 vaccination coverage given the 18% population decline during 2010–2020, potentially limiting USVI's ability to assess vaccination progress. Identifying mechanisms for more reliable population enumeration or improved estimate modeling are essential for accurately guiding USVI public health decision-making.

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Conflicts of Interest: None

Introduction

Vaccination coverage is defined as percentage of persons completing a vaccination series out of a defined target population, often the total population.[1] This metric is a useful tool for COVID-19 response activities, serving as one indicator of progress toward herd immunity.[1] A challenging but fundamental task when estimating vaccination coverage is identifying an appropriate data source to represent this total population denominator and defining that source population in relation to the target population. Ideally, the population represented in the denominator should give rise to the events or persons represented in the numerator (i.e., aligning in geography, demographics, and time). Yet practically, denominator choice is often restricted to data already available and at times, collected for a different purpose.

One such option for population denominators are data sources available through the U.S. Census Bureau (Table). These include the decennial census, which seeks to provide a complete enumeration of the population every 10 years, and the American Community Survey (ACS), which samples a smaller proportion of the population to provide a yearly population estimate.[2,3] Unlike states, District of Columbia (D.C.), and Puerto Rico, U.S. Virgin Islands (USVI) and other smaller territories are not included the American Community Survey (ACS) and only receive a population update every 10 years through the decennial census. A third data source known as the Census Bureau international database (IDB) is often regarded as the preferred population data source for American Samoa, Guam, the Commonwealth of the Northern Mariana Islands, and USVI.[4] IDB is also the primary data source available for the three U.S. freely associated states of The Federated States of Micronesia, the Republic of Palau, and the Republic of the Marshall Islands after their exclusion from the U.S. decennial census in recent decades.[4,5] The IDB estimates are updated yearly and include population size projections up to year 2100. These estimates are modeled using decennial census and other population data sources, as available.

The 2020 decennial census results were delayed because of multiple factors, including data collection interruption by COVID-19.[6] USVI did not receive overarching population counts until October 2021, and complete demographic counts until October 2022.[7] As a result, vaccination coverage and other COVID-19 epidemiologic metrics used to guide the public health response efforts relied on the 2010 decennial census denominator.[8]

Prior studies have described how using outdated population counts can bias epidemiologic estimates due to temporal misalignment of the cases (numerator) and population-at-risk (denominator).[9,10] Gaps in population enumeration are particularly challenging in lower resource international settings.[10,11] However, this challenge has not been well described in U.S. territorial or freely associated state settings. The USVI population is small, with a 2010 decennial census count of 106,405 residents.[7] Therefore, we hypothesized that even slight fluctuations to the population-at-risk would have a meaningful effect on estimated vaccination coverage and thus public health decision-making.

It has been speculated that the USVI population had noticeably changed during 2010–2020, and that changes likely differed by island. For example, in 2012 a major oil refinery that employed approximately 2,000 residents closed on St. Croix Island.[12] In 2017, two category

5 hurricanes struck the territory within two weeks of each other, leaving residents without power for approximately six months and leading to numerous business closures.[13,14] Despite a suspicion of changing population sizes and demographics, the Virgin Islands Department of Health (VIDOH) had to use the 2010 population estimates to guide their COVID-19 and other public health response activities with limited understanding of the expected magnitude of population decline.

We aimed to determine whether using population counts from the 2010 and 2020 decennial census resulted in different vaccination coverage estimates used to inform key public health priorities during the COVID-19 response. A secondary objective was to understand whether using the IDB modeled counts provides a more reliable estimate of vaccination coverage than the 2010 denominator.[15] We sought to answer two overarching questions for each objective using the three population counts: (1) What is USVI's COVID-19 primary series vaccination coverage, and does this differ by island and age group? (2) When did USVI reach a 50% vaccination coverage goal?

Methods

Vaccination coverage estimates overall, by island, and by age

To be eligible for inclusion, individuals had to have at least one COVID-19 vaccination record documented in the USVI vaccination database during December 16, 2020–September 20, 2022 (date of analysis) and be USVI residents as indicated by a valid USVI district (i.e., county equivalent indicating island of residence). Persons were excluded if they were missing the vaccine manufacturer, full vaccine name, and vaccine administered (CVX) code which was required to determine the dosage number needed to complete the vaccination series.

We estimated percentage of persons with a completed primary COVID-19 vaccination series defined as one dose of Janssen (Johnson & Johnson) or two doses of Pfizer-BioNTech or Moderna vaccines received during the study period. Vaccination coverage was calculated as total number of persons who completed primary COVID-19 vaccination series divided by the 2010 and 2020 U.S. Census Bureau total population counts. We similarly calculated vaccination coverage using the 2020 IDB intercensal estimate.[4]

The 2020 decennial census population count is the referent population count for this analysis, given it is the most current and complete enumeration of the population. Bias was defined as the absolute difference between vaccination coverage estimates using the 2020 decennial census population count compared with vaccination coverage estimates using either 2010 decennial census or 2020 IDB population counts.

We stratified vaccination coverage by island of residence (St. Croix, St. John, and St. Thomas [including Water Island]) and by age group (0–19, 20–39, 40–59, and ≥60 years). This was done to investigate whether bias was differential by population demographics relevant to local COVID-19 response resource distribution and policy decision-making (i.e., ensuring vaccine availability across islands and distribution prioritization of higher risk age groups). Vaccination coverage using 2020 IDB denominators was investigated overall and by

age, as no island-level population estimates are provided.[15] Lastly, we present vaccination coverage overall, by island, and by age for receipt of a single vaccine dose.

Tracking vaccination coverage over time

Cumulative vaccination coverage was calculated by estimating daily vaccination coverage for completed COVID-19 primary series using the 2010 and 2020 decennial census and 2020 IDB denominators. This metric was used to identify the date at which 50% vaccination coverage would have been achieved. We also calculated the difference from the date on which 50% vaccination coverage was achieved with USVI's benchmark goal of 50% vaccination coverage of July 1, 2021.

All analyses were conducted in R version 4.1.2 (2021-11-01). This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy.[1]

Results

During the study period 54,739 USVI residents completed a COVID-19 primary vaccination series: 1,820 residents received a single dose of Janssen (Johnson & Johnson) and 52,919 received two doses of either Pfizer-BioNTech or Moderna vaccines (Table S1). According to USVI's decennial census, USVI population declined by 18% (from 106,405 to 87,146) during 2010–2020. 0.2% (128/62,894) of persons were excluded because of missing vaccination name (Table S2) and 3% (1,809/62,894) were excluded because of missing island of residence.

Vaccination coverage estimates overall, by island, and by age

COVID-19 vaccination coverage using the 2020 population count was 12 percentage points higher than coverage using 2010 denominator (2010 denominator: 51%; 2020 denominator: 63%) (Figure 1). Vaccination coverage estimated using the 2020 IDB intercensal estimate was similar to the 2010 decennial census estimate (52%). Using 2020 population counts, vaccination coverage estimates were 11 percentage points higher for St. Thomas and St. Croix, and six percentage points higher for St. John than coverage calculated using the 2010 population counts (Figure 1).

Compared to coverage estimates using the 2020 denominator, vaccination coverage was not meaningfully lower for younger persons (aged 0–19 and 20–39 years) when using the 2010 population count (Figure 1). However, vaccination coverage was 14 percentage points lower for persons aged 40–59 years and 23 percentage points lower for persons aged >60 years when using 2010 population count. The directionality and magnitude of bias in vaccination coverage estimates by age group when using the 2020 IDB intercensal estimate differed from bias observed under the 2010 decennial census: the 2020 IDB vaccination coverage estimates were lower than estimates using both the 2010 and 2020 decennial census vaccination coverage for younger persons (aged 0–19 and 20–39 years). Separately, the IDB vaccination coverage estimate was between the 2010 and 2020 decennial census vaccination coverage estimates for persons aged 40–59 years and >60 years. The magnitude of IDB

[1]§See e.g., 45 C.F.R. part 46, 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.

vaccination coverage overall, by island, and by age were higher when estimating coverage for receipt of at least one COVID-19 vaccine dose (Table S3). However, underestimation observed when using the 2010 decennial census and IDB denominators was similarly observed for COVID-19 primary vaccination series completion.

Tracking vaccination coverage over time

When using the 2010 denominator, 50% vaccination coverage was achieved on January 26, 2022, approximately seven months after the July 1, 2021 goal (Figure 2). However, when using the 2020 denominator, 50% vaccination coverage goal was achieved five months earlier on August 30, 2021, two months after USVI's goal of July 1, 2021. When using the 2020 IDB intercensal estimate, USVI was estimated as reaching the 50% coverage mark on January 25, 2022, one day earlier than the vaccination coverage estimate relying on the 2010 decennial census denominator.

Discussion

Use of both 2010 population counts and IDB intercensal estimates underestimated USVI COVID-19 vaccination coverage, potentially limiting VIDOH's ability to reliably assess their vaccination progress. Bias from temporal misalignment of vaccination counts and the total population was notable, given the 11 and 12 absolute percentage point underestimations using the IDB or 2010 denominator, respectively. Bias was differential by island and age group and altered conclusions about USVI's COVID-19 vaccination progress within USVI.

We found that, in their current form, 2020 IDB intercensal estimates are not reliable for supplying more timely population denominators between censuses for vaccination coverage calculations in USVI. In the vaccination coverage estimation by age group, direction of bias when using the 2020 IDB intercensal denominator was unpredictable, compared with the 2010 and 2020 decennial census denominators vaccination coverage. Specifically, 2020 IDB estimates predicted an increase in the number of persons 0-39 years of age and a decrease in the number of persons 40 years and older, compared to the 2010 decennial census counts. The usefulness of IDB in this setting was further limited by the lack of island-level population estimation.

A limitation of our study is the exclusion of vaccine records that were missing vaccination name (needed to identify primary vaccine series completion) and island of residence. This misclassification would bias vaccination coverage lower and is expected to produce differential bias since missing information differed by age and island. However, bias is expected to be limited as only 0.2% of vaccinated persons were excluded. We were unable to investigate missing island of residence, since missing or invalid geographic information could not be distinguished between a USVI resident missing island information or non-resident with a missing or invalid zip code. USVI residence was required for study inclusion and therefore could induce selection bias. Yet, 97% of persons who completed a primary vaccination series in USVI had a valid USVI island of residence documented. Further, persons vaccinated outside of the USVI would be excluded, which could underestimate the estimated vaccination coverage across all denominators. Lastly, completion of the USVI 2020 decennial census was impacted by COVID-19, and thus, the 2020 decennial

census population count excluded individuals living in group quarters.[6] This contributes to misalignment of the numerator and denominator, in which some persons who receive the vaccine are not reflected in the USVI vaccination database (i.e., source population) despite being included in the target population. The 2010 decennial census documented that 2% of the population lived in group quarters. If the same proportion lived in group quarters at the time of the 2020 decennial census, we may expect negligible overestimation of the 2020 decennial census estimated vaccination coverage, given the small number of persons included in that group. Although the 2020 decennial census is the best available comparison for this analysis, the disruption in survey implementation may have contributed to unmeasured bias in population enumeration.

The findings of this analysis are consistent with previously described challenges and bias in the estimation of epidemiologic measures introduced from using outdated population counts or modeled estimates.[9–11] The context of USVI was similar to lower resource international settings with limited input data sources and where temporal misalignment of numerator and denominator data is more commonplace.[9–11] Our findings add to this literature for smaller population settings, including localities with similar contexts as the U.S. territories and freely associated states. This study highlighted that smaller population settings, especially those with unstable population dynamics like U.S. territories and freely associated states, are particularly sensitive to bias from outdated population counts and modeled population estimates relying on limited and outdated population sources.

Consequences of inaccurate population counts could extend beyond the COVID-19 response. In USVI, population denominators are used to estimate many crucial public health metrics, such as mortality rates and prevalence of disease outcomes. For example, our primary data source used to understand chronic disease outcomes is the Behavioral Risk Factor Surveillance System (BRFSS). This data source relies on population counts to weight survey responses to reflect the demographic distribution of USVI across three islands.[16] Fundamentally, evidence-based public health decision-making in USVI is threatened by a lack of quality denominator data.

At the time of this analysis, 2020 estimates are already expected to be out of date. More frequent population estimates are essential for accurately guiding USVI public health decision-making. Feasibility of including more frequent estimations in territories and freely associated states through inclusion in intercensal surveys (e.g., ACS) and identifying existing or new data sources for improved modeling of IDB intercensal estimates could be explored. This includes improvements for territory-level estimation, and the development of small-area population estimates at the island level. USVI has explored existing local data sources and opportunities for population enumeration through data triangulation. Yet challenges in enumeration remain despite the smaller population size, given the time, funding, personnel, and methodologic sampling expertise needed to identify and collect quality population count data in a resource constrained setting.

Ultimately, relying on 2010 population counts resulted in underestimated vaccination coverage in USVI, and these estimates were not improved by temporally aligned modeled

IDB population counts. Limited data availability is an issue of data equity for smaller U.S. territories, which already experience unique challenges to improving population health.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Note: The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

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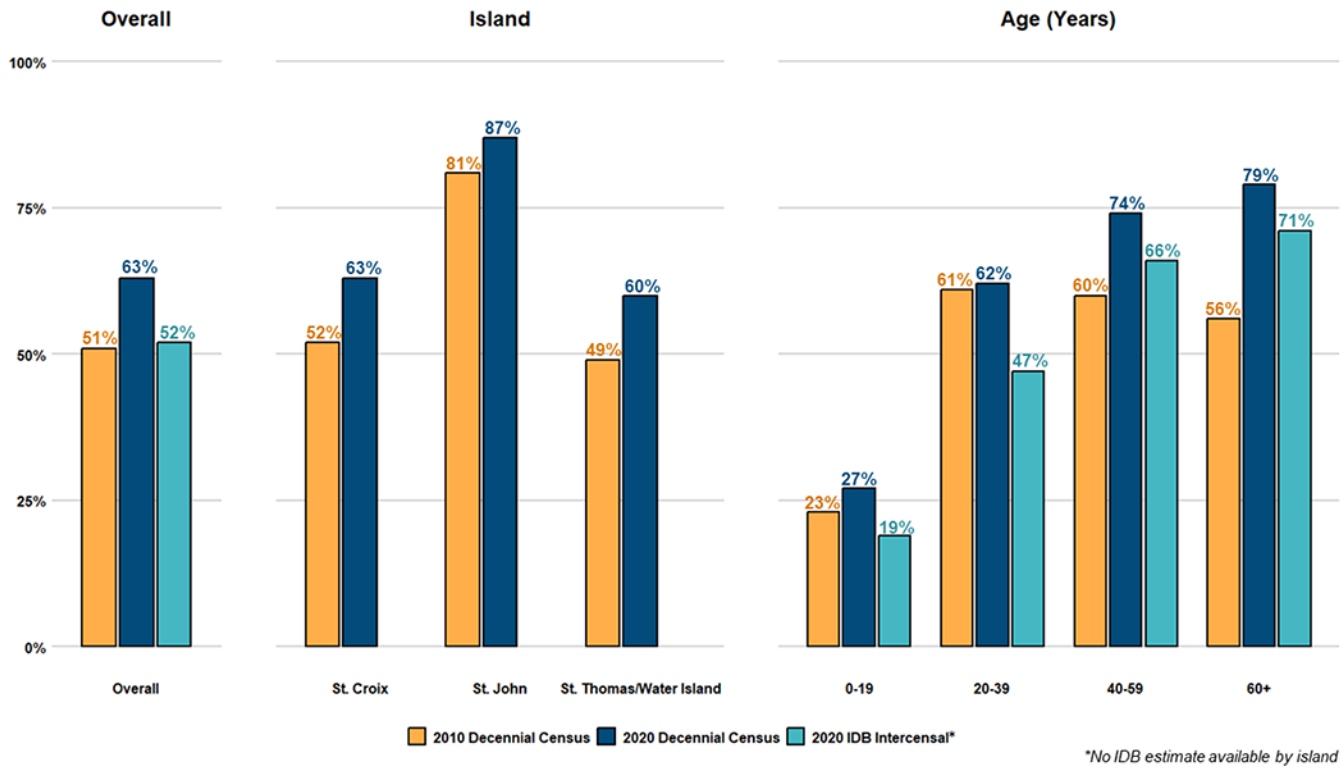

Fig 1.

U.S. Virgin Islands (USVI) COVID-19 completed primary series vaccination coverage by September 20, 2022, using 2010 and 2020 decennial census, and 2020 international database (IDB) intercensal population denominators overall, by island, and by age group

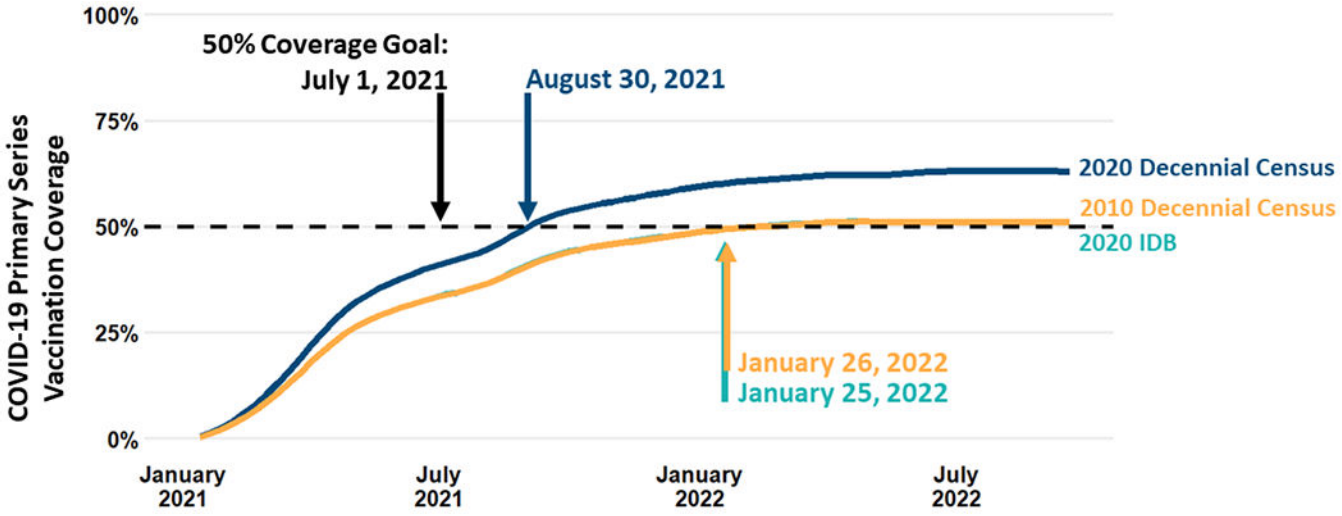

Fig 2.

U.S. Virgin Islands (USVI) COVID-19 primary series vaccination coverage using 2010 and 2020 decennial census population and 2020 international database (IDB) denominators over time, compared with the July 1, 2021, 50% vaccination coverage goal set by USVI

Table.

Select U.S. Census Bureau data sources and their strengths and limitations for use by U.S. territories and freely associated states as population denominators in epidemiologic measures

Denominator Data Source	Data Collection Methods	Strengths	Limitations
American Community Survey[3]	• Population-weighted survey (sample of residents)	• Yearly estimation • Detailed demographic and economic characteristics	• Only available for Puerto Rico • Estimate precision for smaller populations
Decennial Census[2]	• Survey of all residents	• Goal of complete enumeration of the population • Detailed demographic and economic characteristics (for territories)	• Updated every 10 years • Not available for freely associated states
International Database[4]	• Modeled estimates using decennial census and other population data sources as available (e.g., vital statistics)	• Yearly estimation	• Reliant on additional data sources for modeling • No smaller level geography (e.g., county/ island) • Limited demographic strata available (age and sex only)