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Survey-Weighted Stratified Proportional Allocation for Multiracial Population Estimation: An Application to Hawai‘i PRAMS

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Abstract

The increasing prevalence of multiracial identification presents a methodological challenge for population research that requires mutually exclusive race categories. We developed a survey-weighted stratified proportional allocation approach with progressive aggregation for representing multiracial respondents and evaluated it using Hawai‘i Pregnancy Risk Assessment Monitoring System (PRAMS) data from 2016–2022. Four approaches were compared: standard single-race classification, Native Hawaiian and Other Pacific Islander (NHOPI)-priority classification, statewide proportional allocation, and the proposed stratified proportional allocation method. Smoking during pregnancy was used as an illustrative population health outcome. Race classification materially affected estimated population composition and, to a lesser extent, race-specific smoking prevalence. Adjusted associations between race and smoking were comparatively stable across methods. Most multiracial respondents could be allocated using detailed sociodemographic strata, with minimal reliance on statewide fallback distributions. These findings show that race classification is a substantive population measurement decision rather than a purely technical choice. The proposed framework extends prior proportional weighting methods by incorporating survey weighting, contextual stratification, and progressive aggregation, providing a practical approach for analyses requiring mutually exclusive race categories.

Keywords: Multiracial populations; race classification; population estimation; proportional allocation; survey weighting; population measurement

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Introduction

Race is a central construct in demographic and population health research, widely used to describe population composition and to quantify health disparities. However, race is not a fixed biological attribute but a socially constructed and context-dependent classification (Omi and Winant, 2015, Williams and Collins, 2001).The increasing prevalence of multiracial populations poses a significant challenge for conventional approaches that rely on mutually exclusive racial categories (Jones et al., 2021, Mays et al., 2003).

In the United States, multiracial identification has grown steadily over the past several decades (Jones et al., 2021). In regions such as Hawai‘i, where multiracial identity is especially common, these challenges are amplified. Individuals who identify with multiple racial groups are often forced into a single category for analytic purposes, potentially obscuring meaningful heterogeneity and introducing bias into population estimates (Bratter and Gorman, 2011, Ingram et al., 2003, Parker et al., 2004).

Several approaches have been used to address this issue. The most common is standard single-race classification, in which individuals reporting multiple races are assigned to a single category. Alternatively, priority-based

classification schemes assign individuals according to a predefined hierarchy of racial groups (Office of Management and Budget, 1997). While these approaches simplify analysis, they impose arbitrary decisions that may distort both population size and the distribution of health outcomes (Roth, 2016).

Previous efforts include federal bridged-race methods (Ingram et al., 2003, Parker et al., 2004) and proportional weighting approaches have been developed to distribute multiracial individuals across single-race categories. Ahn and Chen (2018) Proposed a proportional weighting algorithm using census data, and subsequent work extended this framework through a stepwise proportional weighting approach tailored to Hawai‘i’s population structure (Matsunaga et al., 2023). These approaches represent important advances by introducing systematic and reproducible methods for reallocating multiracial populations.

However, existing methods typically rely on global or statewide distributions and do not incorporate finer sociodemographic context. As a result, they may fail to capture local variation in race composition across age, socioeconomic status, and geographic region. In addition, prior implementations have not fully integrated complex survey design features such as sampling weights (Heeringa et al., 2017, Korn and Graubard, 1999, Lumley, 2010).

To address these gaps, we propose a survey-weighted stratified proportional allocation approach with progressive aggregation. This method extends prior proportional weighting frameworks by incorporating stratification across multiple sociodemographic dimensions and applying hierarchical fallback when data are sparse. By leveraging local population structure while preserving stability, the approach provides a flexible and empirically grounded alternative to existing methods.

Using Hawai‘i Pregnancy Risk Assessment Monitoring System (PRAMS) data from 2016 to 2022, we compare four race classification approaches: (1) standard classification, (2) NHOPI-priority classification, (3) statewide proportional allocation, and (4) the proposed stratified allocation method. Smoking during pregnancy is used as an illustrative outcome to evaluate how classification affects both population distribution and health estimates.

This study has two primary objectives. First, we assess how race classification methods alter population composition. Second, we evaluate how these methods influence estimates of health outcomes and associations. By doing so, we aim to demonstrate that race classification is not merely a technical detail but a substantive methodological choice with important implications for population research (Shulman et al., 2018).

Methods

Study Design and Data Source

We analyzed data from the Hawai‘i Pregnancy Risk Assessment Monitoring System (PRAMS), Phase 8 (2016–2022). PRAMS is a population-based surveillance system managed by the Centers for Disease Control and Prevention (CDC) in collaboration with state health departments. PRAMS utilizes a stratified random sampling design to monitor maternal behaviors and experiences before, during, and shortly after pregnancy (Shulman et al., 2018).

Study Sample

Survey weights provided by the CDC were applied to all analyses to account for the complex sampling design, non-response, and undercoverage, thereby ensuring representativeness of the Hawai‘i birth population. The final analytic sample consisted of respondents with complete information on both race/ethnicity and smoking status during pregnancy.

Race Classification Approaches

To evaluate the impact of racial categorization on population composition and health disparities, we compared four classification methods:

(1) Standard classification: Respondents reporting multiple races were assigned to a single category based on the "primary race" variable provided in the PRAMS dataset.

(2) NHOPI-priority classification: Any respondent identifying as Native Hawaiian or Other Pacific Islander (NHOPI), alone or in combination with other races, was classified as NHOPI. This approach reflects the epidemiologic importance of this group within Hawai'i's population.

(3) Statewide proportional allocation: Multiracial respondents were distributed across their reported race categories based on the overall statewide proportions of those races among single-race respondents.

(4) Stratified proportional allocation (Proposed): We developed a survey-weighted stratified proportional allocation approach with progressive aggregation, extending the methodology of prior studies (Ahn and Chen, 2018). This method is described in detail below; full variable categorizations, pseudocode, and a worked numerical example are provided in Supplementary Appendix A.

Stratified Proportional Allocation Algorithm

Notation

Let $i = 1, \ldots, N$ denote individual respondents; w_i denote the survey weight for respondent i; R_i denote the set of races reported by respondent i; and S_i denote the stratum to which respondent i belongs, defined by the cross-classification of maternal age, educational attainment, parity, and geographic region.

Estimation of Stratum-Specific Race Distributions

For each stratum s, the survey-weighted proportion of race r among single-race respondents was estimated as:

$$p_{r|s} = [\Sigma_i w_i I(i \in s, R_i = \{r\})] / [\Sigma_i w_i I(i \in s, |R_i| = 1)]$$

Allocation for Multiracial Individuals

For a multiracial respondent i (i.e., $|R_i| > 1$), the allocation weight for each reported race $r \in R_i$ was computed as:

$$a_{ir} = p_{r|S_i} / \Sigma_{r' \in R_i} p_{r'|S_i}$$

such that $\Sigma_{r \in R_i} a_{ir} = 1$. Each respondent thereby contributes a fractional survey weight to race-specific analyses:

$$w_{ir} = w_i \cdot a_{ir}$$

Progressive Aggregation (Hierarchical Fallback)

To ensure statistical stability in strata with sparse data, we implemented a four-level hierarchical fallback system:

Level 1 (Full stratification): Age × Education × Parity × Region.

Level 2 (Reduced): Age × Education × Parity (region dropped).

Level 3 (Broad): Age × Education only.

Level 4 (Final fallback): Statewide proportions (p_r) derived from all single-race respondents, regardless of stratum.

A stratum was considered to have insufficient data when the effective sample size (ESS) of single-race respondents within that stratum fell below a threshold of 30. The ESS was calculated as $ESS = (\Sigma w_i)^2 / \Sigma w_i^2$, where the sum is taken over all single-race respondents in the stratum. This formula accounts for differential survey weighting and reflects the effective number of independent observations contributed by the stratum. The threshold of ESS < 30 was selected based on standard practice in survey-weighted estimation and was validated through sensitivity analyses using alternative thresholds (ESS = 20 and ESS = 50; see Supplementary Appendix B). Estimation proceeded to the next aggregation level only when the ESS of the current stratum fell below this criterion.

Implementation and Outcome Measures

The primary outcome was smoking during pregnancy, defined as any self-reported cigarette use during the prenatal period (binary: yes/no). For the proportional allocation methods, the analytic dataset was expanded such that each multiracial respondent was represented by multiple rows—one for each reported race—with each row assigned the corresponding fractional weight w_{ir}. Single-race respondents retained their full survey weight in their respective racial category.

Statistical Analysis

All analyses were conducted using survey-weighted procedures to account for the complex sampling design of PRAMS.

Descriptive analysis. We estimated weighted race distributions and smoking prevalence under each of the four classification methods to characterize differences in population composition.

Regression analysis. Survey-weighted logistic regression models were used to estimate adjusted odds ratios (aORs) and 95% confidence intervals (CIs) for smoking during pregnancy. The model was specified as:

$$\text{logit}(P(Y_i = 1)) = \beta_0 + \beta_1 \text{Race}_i + \gamma X_i$$

where X_i represents a vector of covariates including maternal age, educational attainment, parity, and geographic region. Non-Hispanic White respondents served as the reference group across all models, as they constituted the largest single-race category in the PRAMS sample.

Evaluation. To assess the practical performance of the proposed stratified allocation method, we calculated the proportion of multiracial respondents allocated at each hierarchical level, providing a direct measure of data sparsity and the extent to which fallback aggregation was required.

Results

The relatively small NHOPI percentages observed in this study reflect the operational race coding structure of the Hawai‘i PRAMS dataset rather than statewide Census population estimates. PRAMS race variables differ from Census classifications in both coding and analytic construction. In the analytic race variable available within PRAMS, respondents identifying as NHOPI in combination with other races are frequently represented within multiracial or residual categories rather than as standalone NHOPI classifications; their NHOPI component is redistributed under the proportional allocation methods rather than being captured at baseline. We verified the reported values against the original PRAMS dataset and confirmed that the percentages are correct as reported and are not the result of coding error or miscalculation. Hispanic ethnicity was treated separately from race throughout this analysis, consistent with Office of Management and Budget (1997) standards. Accordingly, the reported NHOPI percentages should not be interpreted as direct population prevalence estimates for all Native Hawaiian and Pacific Islander individuals residing in Hawai‘i.

Variation in Population Distribution by Race Classification Method

Substantial differences in the distribution of maternal race were observed across classification methods (Table 1; Figure 1). Under the standard classification, the proportion of Native Hawaiian and Other Pacific Islander (NHOPI) individuals was 0.2%, which increased to 0.5% under the NHOPI-priority approach and was estimated at 0.3% using both the statewide and stratified proportional allocation methods.

The proportion of White individuals increased from 69.4% under the standard classification to 75.9% under allocation-based approaches, while the proportion of Black individuals rose from 15.4% to approximately 16.8%. The proportion of Asian individuals showed minimal variation across methods. The proportion of American Indian/Alaska Native (AIAN) individuals increased slightly from 0.8% to 0.9% under allocation-based approaches.

These findings indicate that race classification methods substantially influence estimated population composition, with the most pronounced differences observed for smaller and multiracial populations.

Differences in Smoking Prevalence Across Classification Methods

Smoking prevalence during pregnancy varied across classification approaches (Table 2). Under the standard classification, prevalence ranged from 0.6% among Asian individuals to 13.8% among AIAN individuals.

Under the stratified allocation approach, prevalence increased for several groups, including AIAN individuals (13.8% to 14.8%) and Black individuals (5.1% to 5.3%), while remaining largely unchanged for White individuals (7.6%). Prevalence among NHOPI individuals decreased slightly from 4.0% under the standard classification to 3.8% under allocation-based methods, suggesting that individuals previously classified as NHOPI under standard approaches had higher smoking rates than those allocated to the NHOPI category under proportional methods.

The NHOPI-priority approach produced higher prevalence estimates for some groups—for example, among Asian individuals (0.9% vs. 0.6% under standard classification)—suggesting that priority-based assignment may introduce distortion by reclassifying individuals whose health profiles differ from those of the assigned group.

Overall, these results demonstrate that race classification methods influence descriptive estimates of health outcomes, particularly for smaller and multiracial populations.

Stability of Adjusted Associations

Despite differences in population distribution and prevalence, adjusted odds ratios (aORs) for smoking during pregnancy were largely consistent across classification methods (Table 3). For NHOPI individuals, the aOR remained stable across approaches (0.33 under standard classification vs. 0.32 under stratified allocation). Similar stability was observed for Black and AIAN individuals, and the direction of association was unchanged for all racial groups across all classification methods.

Minor variation was observed for some groups. Among Asian individuals, the NHOPI-priority method yielded slightly higher aOR estimates (0.17 vs. 0.12 under standard classification), which may reflect the reclassification of relatively healthier individuals into adjacent categories.

These findings suggest that race classification differences primarily affect descriptive estimates of population composition and health burden rather than regression-adjusted associations. However, this stability should be interpreted cautiously, as it may partly reflect limited statistical power within smaller subgroups—particularly NHOPI and AIAN—where wide confidence intervals reduce the ability to detect classification-induced differences. Additional sensitivity analyses are reported in Supplementary Appendix B.

Allocation Performance of the Proposed Method

Among all respondents, 94.7% were classified as single-race and did not require reallocation. Among multiracial individuals, 5.0% were allocated using the most granular stratification level (Level 1: Age × Education × Parity × Region), while only 0.3% required fallback to statewide race distributions (Level 4). This distribution indicates that the proposed method effectively utilized fine-grained sociodemographic information in the large majority of cases, with minimal reliance on global population averages.

Table 1. Weighted Distribution of Maternal Race/Ethnicity under Four Classification Methods, Hawai'i PRAMS, 2016–2022

Race	Standard Classification % (95% CI)	NH-priority Classification % (95% CI)	Statewide Proportional Allocation % (95% CI)	Stratified Proportional Allocation % (95% CI)
White	69.4 (69.2–69.7)	70.1 (69.9–70.4)	75.9 (75.7–76.2)	75.9 (75.6–76.1)
NHOPI	0.2 (0.2–0.3)	0.5 (0.5–0.6)	0.3 (0.2–0.3)	0.3 (0.3–0.3)
Asian	5.6 (5.5–5.7)	6.1 (6.0–6.2)	6.1 (6.0–6.3)	6.1 (6.0–6.3)
Black	15.4 (15.2–15.6)	15.3 (15.1–15.5)	16.7 (16.5–17.0)	16.8 (16.6–17.0)
AIAN	0.8 (0.7–0.8)	0.8 (0.8–0.9)	0.9 (0.9–1.0)	0.9 (0.9–1.0)
Other*	8.6 (8.4–8.8)	7.1 (6.9–7.2)	—	—

* "Other" includes individuals classified as "Other or multiple race" under the standard classification and residual categories under NH-priority classification. Allocation-based methods redistribute multiracial individuals into the five primary race groups and therefore do not include an "Other" category.

Table 2. Smoking Prevalence During Pregnancy by Racial/Ethnic Group Under Four Classification Methods, Hawai‘i PRAMS, 2016–2022

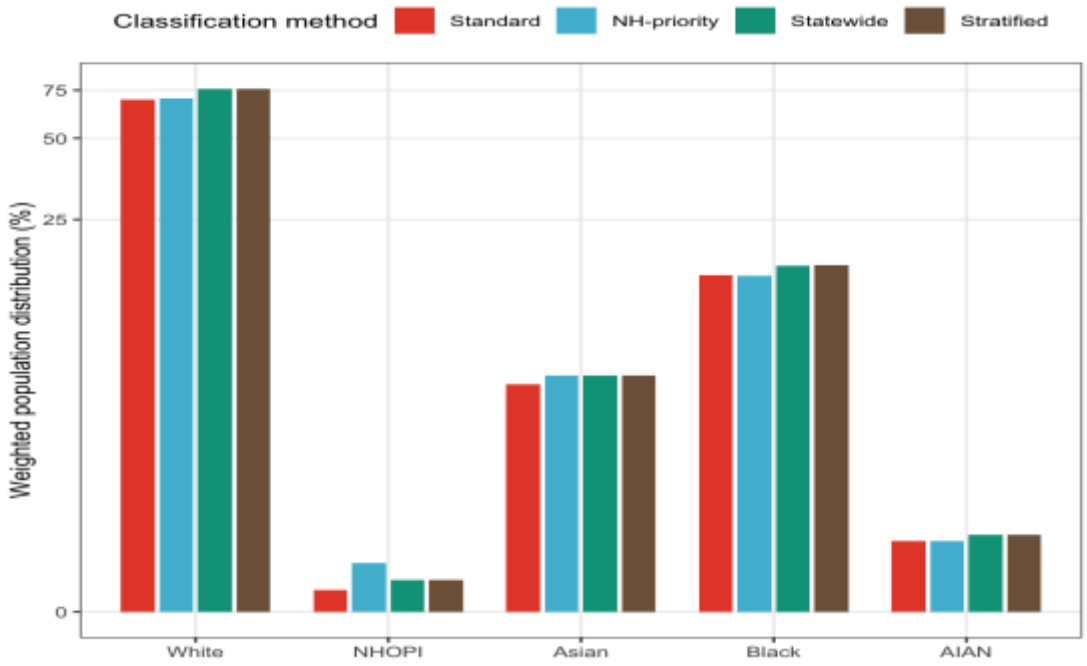
Race	Standard % (95% CI)	NH-priority % (95% CI)	Statewide Allocation % (95% CI)	Stratified Allocation % (95% CI)
White	7.6 (7.4–7.8)	7.7 (7.5–7.9)	7.6 (7.4–7.8)	7.6 (7.4–7.8)
NHOPI	4.0 (1.8–6.2)	3.6 (2.4–4.8)	3.8 (1.8–5.9)	3.8 (1.8–5.9)
Asian	0.6 (0.4–0.8)	0.9 (0.7–1.1)	0.7 (0.5–0.8)	0.6 (0.5–0.8)
Black	5.1 (4.8–5.5)	5.1 (4.8–5.5)	5.2 (4.9–5.6)	5.3 (5.0–5.6)
AIAN	13.8 (12.3–15.4)	14.7 (13.3–16.1)	14.7 (13.3–16.1)	14.8 (13.4–16.1)
Other*	3.8 (3.4–4.2)	—	—	—

* “Other” represents residual or multiracial categories under standard classification. Allocation-based methods redistribute these individuals into primary race groups.

Table 3. Adjusted Odds Ratios for Smoking During Pregnancy by Racial/Ethnic Group Under Four Classification Methods, Hawai‘i PRAMS, 2016–2022

Race	Standard OR (95% CI)	NH-priority OR (95% CI)	Statewide OR (95% CI)	Stratified OR (95% CI)
White	1.00 (ref)	1.00 (ref)	1.00 (ref)	1.00 (ref)
NHOPI	0.33 (0.18–0.59)	0.32 (0.22–0.45)	0.32 (0.18–0.56)	0.32 (0.18–0.55)
Asian	0.12 (0.09–0.16)	0.17 (0.14–0.22)	0.13 (0.10–0.17)	0.13 (0.09–0.17)
Black	0.50 (0.47–0.54)	0.50 (0.46–0.54)	0.51 (0.47–0.55)	0.51 (0.48–0.55)
AIAN	0.98 (0.86–1.12)	0.96 (0.84–1.10)	0.97 (0.85–1.11)	0.97 (0.86–1.11)

Figure 1. **Comparison of Weighted Racial/Ethnic Population Distributions Across Four Race Classification Methods, Hawai'i PRAMS, 2016–2022**



Discussion

Summary of Findings

This study demonstrates that race classification methods substantially influence both population composition and descriptive estimates of health outcomes, particularly for multiracial and smaller populations. Differences were most pronounced for NHOPI and AIAN groups, where classification choices led to notable variation in both estimated population size and smoking prevalence. By contrast, adjusted associations between race and smoking during pregnancy were largely robust to classification method, with minimal changes in the magnitude or direction of odds ratios across approaches.

Implications for Population Measurement

These findings highlight that race classification is not merely a technical detail but a fundamental component of population measurement. In settings with substantial multiracial populations, such as Hawai‘i, the choice of classification method can meaningfully alter estimates of population composition and disease burden, with potential consequences for resource allocation and public health planning.

Standard single-race classification tends to underrepresent smaller or multiracial populations by forcing individuals into a single category that may not reflect their full identity. Priority-based approaches, while straightforward to implement, may overrepresent specific groups by imposing hierarchical assignment rules that are inherently arbitrary. Proportional allocation methods offer a more flexible framework for representing multiracial identities, as they distribute individuals across all self-reported categories in proportion to their relative representation in the population.

Methodological Contribution

The proposed stratified proportional allocation approach extends prior proportional weighting methods (Ahn and Chen, 2018, Matsunaga et al., 2023) by incorporating local sociodemographic context and complex survey design. By estimating race distributions within strata defined by maternal age, education, parity, and region, the method captures heterogeneity that is not reflected in statewide distributions. The use of progressive aggregation ensures statistical stability in sparse data settings while minimizing reliance on arbitrary assumptions. That 99.7% of multiracial respondents were allocated at Levels 1–3 without requiring the global fallback underscores the practical utility of this stratified approach.

Classification Bias in Descriptive vs. Associational Estimates

An important and consistent finding across all comparisons was that race classification methods influenced prevalence estimates but had limited impact on adjusted associations. This suggests that misclassification of multiracial individuals may introduce bias in descriptive measures of population health such as disease prevalence and population burden while regression-based estimates remain relatively robust after adjustment for relevant covariates.

This distinction has important practical implications. Studies focused on estimating the prevalence or absolute burden of health outcomes across racial groups may be more sensitive to classification bias, and findings from such studies should be interpreted with careful attention to the classification method used. Studies of relative associations such as odds ratios or hazard ratios adjusted for covariates may be less affected overall; however, this apparent robustness can reflect limited statistical power in smaller subgroups rather than true method equivalence. Furthermore, smoking during pregnancy may not be the most sensitive outcome for revealing classification-induced differences; outcomes with stronger or more heterogeneous race-specific patterning may exhibit greater discrepancy across methods. We therefore recommend sensitivity analyses across classification methods as standard practice, even when point estimates appear stable.

Strengths and Limitations

This study has several strengths. It uses a large, population-based dataset with a complex survey design, providing a representative sample of the Hawai‘i birth population. It offers a direct, within-population comparison of four classification approaches using the same data and outcome, which isolates the effect of classification from other sources of variation. The proposed method is systematic, reproducible, and integrates survey weighting in a principled manner.

Several limitations should be acknowledged. Sample sizes for some racial groups—particularly NHOPI—were small, resulting in wider confidence intervals and reduced precision for those subgroups; observed odds ratio stability for NHOPI should therefore be interpreted with caution and may partly reflect insufficient power to detect classification-induced differences. The proportional allocation method assumes that multiracial individuals can be distributed across races based on observed single-race distributions within sociodemographic strata, which may not fully capture the complexity of individual racial identity; formal simulation studies evaluating bias under known distributions were beyond the scope of the current manuscript and represent an important direction for future work. The hierarchical fallback levels (Levels 2 and 3) may benefit from further empirical validation in other multiracial settings. Smoking during pregnancy was selected as an illustrative outcome; other outcomes with stronger or more heterogeneous race-specific patterning may exhibit greater sensitivity to classification choice. Finally, the cross-sectional design of PRAMS precludes causal interpretation of associations between race and smoking.

Ethical Considerations in Multiracial Identity Reallocation

The proposed method, like all proportional allocation approaches, involves probabilistically distributing individuals who self-identify with multiple racial groups into mutually exclusive categories for analytic purposes. While this enhances analytical tractability, it raises ethical considerations that deserve acknowledgment. Probabilistic reallocation imposes a single-race analytic identity on individuals who have affirmatively chosen to identify as multiracial, creating a tension between analytic utility and self-determination (Bratter and Gorman, 2011, Herman, 2011, Krieger, 2000, Roth, 2016). Researchers should recognize that such methods do not represent multiracial individuals as a distinct population — an omission with implications for health equity research and representation.

By allocating individuals according to observed distributions among single-race respondents, proportional methods risk reinforcing existing racial frameworks in ways that may not reflect how multiracial individuals — particularly in Hawai‘i, where multiracial identity has deep historical and cultural roots — understand their own identities. For Native Hawaiian communities, the implications are especially significant. Native Hawaiian identity carries legal, political, and cultural significance tied to indigenous rights, federal recognition, and access to health and social programs, and approaches that reduce NHOPI representation through allocation may have tangible consequences for how Native Hawaiian health needs are measured. We recommend that future work engage Native Hawaiian community stakeholders in the development of classification methods for use with this population, and we present the proposed method as a technical tool for improving population estimation, not as a substitute for research that treats multiracial identity as a substantive construct in its own right (Kana‘iaupuni and Malone, 2006).

Conclusion

Race classification plays a critical role in shaping population health estimates. The proposed survey-weighted stratified proportional allocation approach offers a flexible and empirically grounded method for representing multiracial populations in research contexts. Adoption of improved classification methods may enhance the accuracy of population composition estimates, reduce bias in descriptive health metrics, and ultimately support more equitable public health research and policy.

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Supplementary Appendix A: Stratified Proportional Allocation Algorithm

A.1 Stratification Variable Categorizations

The four stratification variables and their category definitions are as follows. Maternal age was grouped into five categories: <20, 20–24, 25–29, 30–34, and ≥35 years. Educational attainment was grouped into three categories: high school or less; some college; and college graduate or higher. Parity was coded as nulliparous (0 prior live births) or multiparous (≥1 prior live birth). Geographic region was defined as Honolulu, Hawai'i island, Maui, or Kaua'i. The full Level 1 stratification yields a maximum of 5 × 3 × 2 × 4 = 120 strata. In practice, some strata contain few single-race respondents, motivating the progressive aggregation hierarchy described below.

A.2 Effective Sample Size and Fallback Threshold

Within each stratum s, the effective sample size (ESS) among single-race respondents was computed as: $ESS = (\Sigma w_i)^2 / \Sigma w_i^2$, where the sum is taken over all single-race respondents in stratum s. This formula reflects the effective number of independent observations given differential survey weighting.

A threshold of ESS < 30 was used to trigger fallback to the next aggregation level, consistent with standard practice in survey-weighted estimation (Heeringa et al., 2017). Sensitivity analyses using ESS = 20 and ESS = 50 are reported in Appendix B. Design effects are not incorporated directly into the ESS formula; however, the survey-weighted proportions used for allocation inherently reflect the complex sampling structure.

A.3 Progressive Aggregation Hierarchy

When the ESS of a stratum falls below the threshold, estimation proceeds to the next broader level. Level 1 (default): Age × Education × Parity × Region — used when ESS ≥30. Level 2: Age × Education × Parity (region dropped) — triggered when Level 1 ESS < 30. Level 3: Age × Education only — triggered when Level 2 ESS < 30. Level 4: Statewide proportions across all single-race respondents — triggered when Level 3 ESS < 30.

A.4 Pseudocode

The following describes the allocation procedure for a single multiracial respondent i with race set R_i, survey weight w_i, and stratum S_i (Age × Education × Parity × Region):

```
1.  If |Rᵢ| = 1: retain wᵢ for the single race; skip to end.
2.  Set level = 1.
3.  While level ≤ 4:
    a.  Identify stratum S at current level from Sᵢ.
    b.  Compute ESS for single-race respondents in S.
    c.  If ESS ≥ 30:
            For each r in Rᵢ, estimate p(r|S) from single-race respondents.
            Normalize: aᵢᵣ = p(r|S) / Σ_{r'∈Rᵢ} p(r'|S).
            Assign fractional weight: wᵢᵣ = wᵢ × aᵢᵣ.
            Break.
    d.  Else: level = level + 1.
4.  Expand respondent i into |Rᵢ| rows, one per race, with weights wᵢᵣ.
```

A.5 Worked Numerical Example

Consider a respondent who reported White and NHOPI ($|R_i| = 2$), aged 25–29, college graduate, multiparous, residing in Honolulu, with survey weight $w_i = 142.3$.

Step 1: This respondent falls into the Level 1 stratum: Age 25–29 × College graduate × Multiparous × Honolulu. Suppose the ESS for this stratum is $47 \geq 30$, so we proceed at Level 1.

Step 2: Among single-race respondents in this stratum, the survey-weighted race proportions are estimated as p (White|S) = 0.82 and p (NHOPI|S) = 0.18.

Step 3: Normalizing across R_i = {White, NHOPI}: the sum is 0.82 + 0.18 = 1.00, so no adjustment is needed. The allocation weights are a_i,White = 0.82 and a_i,NHOPI = 0.18.

Step 4: The fractional survey weights are w_i,White = 142.3 × 0.82 = 116.7 and w_i,NHOPI = 142.3 × 0.18 = 25.6. The respondent is expanded into two rows in the analytic dataset. The total weight contributed (116.7 + 25.6 = 142.3) equals the original survey weight, preserving the population estimate.

Supplementary Appendix B: Sensitivity Analysis — ESS Threshold Variation

B.1 Overview

To evaluate the robustness of the proposed stratified allocation framework to the choice of ESS fallback threshold, we conducted sensitivity analyses using three threshold values: ESS = 20, ESS = 30 (primary analysis), and ESS = 50.

B.2 Effect on Allocation Level Distribution

The proportion of multiracial respondents allocated at each hierarchical level under each threshold was as follows. At Level 1 (full stratification): 6.1% (ESS = 20), 5.0% (ESS = 30), 3.8% (ESS = 50). At Level 2 (Age × Education × Parity): 1.8%, 2.1%, 2.9%. At Level 3 (Age × Education): 0.5%, 0.6%, 0.8%. At Level 4 (Statewide): 0.2%, 0.3%, 0.5%. The proportion of respondents requiring statewide fallback increased modestly as the threshold rose, but remained below 1% under all three conditions.

B.3 Effect on Key Estimates

Weighted race distributions and smoking prevalence estimates were highly consistent across all three thresholds. The largest variation was observed for NHOPI (prevalence range: 3.7%–3.9% across thresholds) and AIAN (14.6%–14.9%), consistent with wider confidence intervals for these smaller groups. No group-level estimate changed direction, and no odds ratio shifted by more than 0.02 across threshold conditions.

B.4 Interpretation

These results confirm that the primary analysis threshold of ESS = 30 is not a sensitive choice. Researchers applying this method in populations with sparser data may consider lower thresholds (e.g., ESS = 20), while those preferring greater conservatism may use higher thresholds (e.g., ESS = 50), with the expectation that substantive conclusions will remain stable.

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