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A matter of perception: Perceived socio-economic status and cortisol on the island of Utila, Honduras

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Abstract

Objectives: Numerous studies link low objective and subjective socioeconomic status (SES) to chronic activation of the hypothalamic pituitary adrenal (HPA) axis. Here, we examine associations between objective and subjective SES and diurnal salivary cortisol, a primary HPA component, as well as demographic and ecological predictors associated with SES perceptions and changes in diurnal cortisol.

Methods: Participants were residents (age 18–79, $n = 61$) of Utila, a Honduran island where economic disparities are overt and geographically contained. Objective SES was measured as a composite of income, education, and occupation. Subjective SES was measured with a MacArthur ladder and a perceived lifestyle discrepancy (PLD) scale. Salivary cortisol was collected three times per day for two days. Questions addressing demographic, social, and household characteristics were assessed as predictors of PLD.

Results: Assessed independently, objective SES ($P = .06$) and PLD ($P = .003$) were associated with the steepness of diurnal cortisol changes, while PLD was also associated with higher cortisol area under the curve (AUC) ($P = .036$). Modeled together, only PLD predicted diurnal slope and AUC. PLD was associated with household sanitation, immigration status, food scarcity, objective SES, and owing money. Only access to sanitation and owing money had direct associations with cortisol that were not mediated by PLD.

Conclusions: For adults on Utila, perceptions of unmet need outweigh other social and economic status factors in predicting cortisol AUC and slope. In addition, the unmediated effects of access to sanitation and owing money on cortisol suggest that these distinct aspects of inequality are important to consider when seeking to understand how inequality can impact HPA function.

1 | INTRODUCTION

Numerous studies have linked lower socioeconomic status (SES) and greater wealth inequality to incidence of chronic disease and other health outcomes (Agbedia et al., 2011; Dressler, 1994; Singh-Manoux, Marmot, & Adler, 2005). This relationship is thought to be mediated, at least in part, by psychosocial stress and hypothalamic-pituitary-adrenal (HPA) axis function (Adler, Marmot, McEwen, & Stewart, 1999; Taylor & Seeman, 1999; Wright & Steptoe, 2005). As a primary component of the neuroendocrine system, the HPA axis regulates the body's response to stress through adjustment of the release of glucocorticoids, such as cortisol. Through its relationship with glucocorticoid release, the HPA axis modulates how psychological and physical experience impact physiological functions such as glucose metabolism (Nicolson, 2007). However, SES may impact stress and HPA function in myriad ways, and the particular aspects of the socioeconomic environment that most directly affect stress and salivary cortisol have not yet been fully characterized. These might include direct correlates of SES, such as access to material resources (e.g., quality diet, adequate shelter, or health care), as well as the indirect effects of intangible stressors (e.g., perceptions of unequal distribution of resources, lack of status or ability to secure resources) (Worthman & Kohrt, 2005).

Much health disparity research addressing the role of SES focuses on objective measures such as income, education, and employment access (Adler & Newman, 2002; Williams & Collins, 2001; Winkleby, Jatulis, Frank, & Fortmann, 1992). In relation to SES and cortisol, in the Multi-Ethnic Study of Atherosclerosis (MESA), Hajat and colleagues (2010) found that low objective SES individuals had blunted salivary cortisol awakening responses as well as a less steep decline during the early part of the day. While objective measures may reflect absolute deprivation or unequal access to resources, they fail to capture less obvious aspects of an individual's life, such as childhood conditions, household conditions, perceived mobility, social networks and community influences, that could inform the "lived experience" of poverty and inequality (Duesenberry, 1949; Richmond, Elliott, Matthews, & Elliott, 2005).

Similar stressors may be perceived differently by different individuals, thus measuring perceptions can tell us whether an experience is acting as a cue of stress for a particular individual. Perceptions, therefore, may further mediate how inequalities 'get under the skin' and affect the neuroendocrine processes. Perceived, or subjective, SES has been suggested as an important aspect of SES because of its potential to (a) act as a composite self-weighted evaluation of multiple types of objective SES, and (b) consider the effect of social comparisons with different reference groups, which captures how a certain objective level of wealth or status may have variable impacts on stress and health among individuals (Marmot & Wilkinson, 1999; McDade, 2001; Operario, Adler, & Williams, 2004). For example, Ranjit, Young, and Kaplan (2005) found that perceiving material hardship was linked to a more blunted cortisol awakening response, as well as a less steep decline in diurnal salivary cortisol over the course of the day. Other studies show similar relationships between material deprivation and salivary measures of cortisol, with some evidence suggesting these relationships can persist through generations (Nepomnaschy & Flinn, 2009; Thayer & Kuzawa, 2014).

Despite the recognition that subjective SES can capture multiple aspects of SES, such measures are less common in studies of HPA function and salivary diurnal cortisol relative to objective SES measures. Additionally, research identifying the most salient aspects of subjective experience, and their underlying environmental correlates, is scant, especially in less industrial contexts where the interaction of social and economic capital may differ from industrialized societies (cf: McDade, 2001; Nyberg, 2012; Squires et al., 2012; von Rueden et al., 2014). Though research exists, these methods are less common than most others, likely due, in part, to the challenges of reliably measuring subjective SES, as well as the challenges of collecting high-quality data on salivary diurnal cortisol in the field. However, unpacking the role that objective and subjective aspects of SES play in the experience of psychosocial stress, and concomitant changes in cortisol, may help explain the persistent associations between SES and health at both low and high ends of the spectrum, and even across fine status differences (von Rueden et al., 2014; Worthman & Kohrt, 2005).

1.1 | HPA axis, salivary cortisol, and psychosocial stress

Activation of the HPA axis has been posited as a means by which psychosocial stress affects other physiological systems (Evers et al., 2010; Hellhammer, Wüst, & Kudielka, 2009; McEwen, 2012; Miller et al., 2009). Studies in humans, nonhuman primates and rodents have concluded that situations characterized by novelty, unpredictability, low perceived control, and other psychosocial challenges (e.g., interpersonal conflicts) reliably stimulate the HPA axis (Dickerson & Kemeny, 2004; Flinn, Nepomnaschy, Muehlenbein, & Ponzi, 2011; Hennessy, Kaiser, & Sachser, 2009; Rose, 1984; Sapolsky, 2004). The associated response is characterized by the production of cortisol, a glucocorticoid hormone released by the adrenal glands. HPA activation helps direct glucose, fatty acids, and other resources to tissues necessary for facing such acute environmental challenges (Flinn et al., 2011).

The diurnal rhythm of cortisol is typically characterized by a sharp spike about 30–45 minutes after waking (known as the cortisol awakening response or CAR), and a relatively steady decline throughout the day (Friedman, Karlamangla, Almeida, & Seeman, 2012; Wüst et al., 2000). Blunting of the diurnal rhythm may be driven either by a reduced awakening response, or a failure of cortisol levels to decline over the course of the day; blunting by reduced awakening response and/or non-declining diurnal levels can be captured through cumulative cortisol exposure, or area under the curve (AUC) (Nicolson, 2007; Seeman, Singer, Ryff, Dienberg Love, & Levy-Storms, 2002; Wüst et al., 2000). Exposure to psychosocial strain can alter diurnal cortisol in several ways, dependent upon type, severity and persistence of the stressor (Miller, Chen & Zhou, 2007). Altered cortisol may be characterized by overall elevated cortisol levels and flattened departures from the typical diurnal pattern, as well as dampened cortisol responsiveness (Saxbe, 2008). Cortisol dysregulation is defined here as alterations in HPA function resulting in either a blunted diurnal rhythm or excessively high or low levels of cumulative salivary cortisol throughout the day (AUC), that lead to a departure from the usual circadian rhythm (Seeman et al., 2002; Weinrib et al., 2010).

In humans, the sensitivity of the HPA axis to psychosocial stressors may also aid the development of social competencies (Flinn, 2006). Plasticity in the HPA response is imperative in maintaining an organism's ability to respond to perturbations in the environment. However, chronic over-activation of this system due to persistent psychosocial stress can precipitate a dysregulation of the diurnal rhythm of cortisol. Chronic adverse social experiences like persistent poverty, perceived inability to cope, and issues surrounding migration and acculturation have been linked to cortisol dysregulation (Desantis, Kuzawa, & Adam, 2015; Miller et al., 2007). For instance, Desantis and colleagues have shown that the cumulative effects of low objective SES from the prenatal period to young adulthood predict flatter diurnal cortisol rhythms more consistently than current SES based on cross-sectional data (Desantis et al., 2015). Cortisol dysregulation has been related to immune deficiency, cognitive impairment and deleterious health outcomes, including hypocortisolism (e.g., Addison's Disease), hypercortisolism (e.g., Cushing Syndrome), depression, fatigue, central adiposity, and glucocorticoid resistance (Champaneri et al., 2013; Flinn, 2006; Jarcho, Slavich, Tylova-Stein, Wolkowitz, & Burke, 2013; Webster Marketon & Glaser, 2008; Weinrib et al., 2010). The exact processes by which stress leads to these similarly adverse but variant outcomes remain poorly understood, though they are likely traced back to long-term experience of chronic stress which permanently alters the HPA axis (Gillespie, Phifer, Bradley, & Ressler, 2009; Heim et al., 2000; Lemieux & Coe, 1995).

1.2 | Status and subjective measures of SES

To investigate the influence of SES on HPA function, we define subjective SES as the subjective experience of access to resources, including perceptions of how one's access to material wealth compares to what one thinks is necessary or desirable to achieve, and what one's perceived social standing is relative to others (Agbedia et al., 2011; Mullainathan & Shafir, 2013). These relative evaluations of social status are likely important because humans have evolved to be both status seeking and sensitive to relative rank in social hierarchies (Franz, Mclean, Tung, Altmann, & Alberts, 2015; Gesquiere et al., 2011). In many societies, high status is associated with greater reproductive success in men (von Rueden & Jaeggi, 2016) and better health status for both sexes (Hu, Adler, Goldman, Weinstein, & Seeman, 2005; Ostrove, Adler, Kuppermann, & Washington, 2000). Strategies for status competition can be coordinated by evolved mechanisms such as social comparison (Gilbert, Price, & Allan, 1995). Because humans are sensitive to cues of low status and are often motivated to improve their status, low perceived social standing in relation to others may be a source of psychosocial stress (von Rueden et al., 2014). In addition, the extent to which individuals use social information to calibrate their own lifestyle needs may affect their perception of adequacy or failure in establishing a secure environment. If individuals pursuing higher status attend to social norms to determine the relative adequacy of resource holdings, then perceptions of inadequacy may lead to psychosocial stress (Azar 2004; Costanza et al., 2007). Persistent psychosocial stress may lead to over-activation of the HPA axis and dyregulation, observed as excessively high or low AUC cortisol or a blunted diurnal slope.

1.3 | Objectives and hypotheses of the current study

Here, we relate objective and subjective SES to two primary measures of HPA function: diurnal slope in salivary cortisol (i.e., rate of decline from morning to evening), and total daily salivary cortisol exposure (i.e., AUC) among individuals on the Honduran island of Utila. We predict that both objective and subjective SES will affect HPA function. Specifically, lower SES will be related to a cortisol profile associated with chronic stress: higher AUC and blunted diurnal slope. Furthermore, we predict an association between subjective SES and cortisol independent of the effect of objective SES. Following our primary goal of determining whether subjective SES is a predictor of diurnal cortisol, we explore factors that might predict subjective SES perceptions by influencing exposure to inequality or resource stress, including age, immigration status, household size and composition, neighborhood, household sanitation, food security, financial security, and employment in the tourism industry. For these factors we determine whether they are related to subjective SES measures, and whether they also predict diurnal cortisol profiles.

1.4 | Ethnographic context

Our research investigates adults (18–79) living on Utila, one of the most heavily touristed Honduran Bay Islands. Utila is home to Utilian natives of British and American ancestry, and immigrants from mainland Honduras. Utila represents a unique microcosm for investigating the effects of subjective SES on stress, as substantial inequalities exist between the island's inhabitants, as well as between the island's inhabitants and the tourists, which may lead to opportunities for social comparison across wide socioeconomic disparities.

The Honduran Bay Islands consist of three major islands and 52 cays (Stonich, 2000). Between 1834 and 1836, the Utila cays were settled by a small number of British families from the Cayman Islands. These families, along with two American farmers settling around the same time, comprise the base of the island's cultural and genealogical history (Rose, 1904). Though officially under Honduran rule, the predominant, while unofficial, language on the island continues to be English, and is the sole language spoken by most elder Utilians today.

Utila remained relatively isolated until the middle of the twentieth century, when it expanded its agricultural exports to meet United States' import interests (Currin, 2002). American goods (e.g., housing materials, interior design goods and clothing) became enmeshed in Utilian culture, as they comprised, almost exclusively, the commodities bought and sold in the Bay Islands. The mid-twentieth century also marked the start of the remittance economy. Currently, many working age Utilian men spend 4–8 months annually offshore and send money back to their families on the island.

Coinciding with the remittance economy was an increase in the immigration of Hondurans from the mainland. The majority of Hondurans live in an area called *Camponado* that currently contains over 100 families, with a population over 1,000. According to the 2012 census, the island's total population was only 3,580. Camponado extends into the swampy interior of the island, suffers from poor sanitation, and is stigmatized as the poorest and most dangerous part of the island. Factors such as increased gang violence on the mainland and the destruction from Hurricane Mitch in 1998, have led many Hondurans to seek out resettlement on Utila. When asked about why they came to Utila, Hondurans report intentions for seeking work, "*una vida mejor*" (a better life), or "*una vida más tranquila*" (a more peaceful life). Other reports attest to hardships on the mainland: "*la vida es dura en Honduras*" (life is hard on the mainland) and "*la vida es peligrosa en la costa*" (life is dangerous on the mainland). Expansion of the mainland Honduran immigrant population is considered to be a driving force behind the socioeconomic disparity on Utila, as the influx of immigrants is perceived to have exacerbated competition for jobs and precipitated rapid cultural change (Currin, 2002).

On Utila, economic growth has been coupled with an increase in socioeconomic inequality as gains are unequally distributed. There is substantial variation in access to resources and opportunities for advancement on the island. Utilians and foreign proprietors are the major business owners—owning and operating the dive shops around which the tourist economy is centered (Stonich, 2000). In contrast, Hondurans work primarily in service industry jobs as unskilled laborers, house cleaners and cooks. However, even tourism is unpredictable and provides only limited and seasonal employment; so for both groups there remain few stable opportunities for economic advancement on the island.

The influx of tourists has led to a greater overall exposure to luxury and lifestyle indulgences for both Utilians and Hondurans. Utilians in general tend to have a greater potential for upward mobility and may strive for a relatively higher socioeconomic lifestyle than most Hondurans, though actually attaining a higher standard of living remains difficult. Conversely, Hondurans have worse prospects for upward mobility due to their relative marginalization, live in greater squalor, and may experience stress as a result of their lower relative socioeconomic standing. Therefore, despite the potentially different scales of absolute deprivation, both groups may perceive their environments as competitive and resource deprived.

2 | METHODS

2.1 | Participant recruitment

Participants were recruited through a local health clinic, whose clients are primarily Honduran, and a health outreach campaign on HQTV (the Utila TV station). Sixty-one adult participants (19 men and 42 women) were recruited between July and December 2013 (see Descriptive Statistics in Table 1 and Supporting Information Table S1). Individuals in the study were between the ages of 18–79. Pregnant women were not included in the study due to hormonal changes during pregnancy (Obel et al., 2005). Participants were interviewed in either English or Spanish, depending on their preferred language, in a private setting. Interviews included questions on family composition, economic status, social integration, environmental stressors, and health history.

2.2 | Human subjects approval

All data collection protocols were approved by the Institutional Review Board at the University of California Santa Barbara. The project and protocols were also approved by the local Honduran governance and the community health center on Utila. All study participants provided informed consent.

2.3 | Composite objective SES measure

An objective SES measure was created as a composite of years of schooling, income, and occupational rank, following McDade (2001). Income was measured by an individual's monthly household income in a typical month, recorded categorically (0–5,000; 5–10,000; 10–20,000; 20–40,000; 40,000+ Honduran Lempira per month; 20 Lempira = ∼1 USD). Categorical income was used because the income of most islanders varies from month to month. Educational attainment was measured by highest year in school attained, including years in college or trade school. Occupational rank was indexed between 1 and 3, using scoring from McDade (2001): 1 = unemployed or non-income earning (e.g., housewife); 2 = unskilled wage labor (e.g., domestic help, street vendor); 3 = skilled labor/professional (e.g., teacher, doctor, business owner). These rank-scores were validated through interviews with key informants regarding locally-defined occupational prestige. Occupational rank was assigned as the highest rank among members in the household. For example, if the participant cleaned houses (score of 1), but her spouse was a teacher (score of 2), her occupational rank would be a 2. Each variable was z-scored, then a composite objective SES variable was created by summing across the variables. Finally, since remittances are a part of the Utilian economic structure, in addition to the objective SES measure, participants were asked "Did you receive any remittances or did anyone send you money in the last month?" and "Did you send remittances/money to anyone in the last month?" Remittances were not included in the composite SES variable but analyzed as a separate variable.

2.4 | Subjective SES measures: Perceived lifestyle discrepancy and MacArthur ladder

2.4.1 | The discrepancy between current wealth and perceptions of need

Previous measures of subjective SES (e.g., Dressler's (1996) model of *cultural consonance* and McDade's (2001) and Sorenson et al.'s (2005) model of *lifestyle incongruity*) have sought to understand how an individual's ability to adequately meet a culturally-defined sufficient lifestyle impacts his or her psychosocial stress and/or health. Our measure of lifestyle discrepancy seeks to add an additional dimension to these previous measures by looking at how individual perception of one's own SES measures up to their own assessment of need. Though this perception is likely informed by local cultural norms, perceived discrepancy should capture any individual variation in perceived lifestyle needs.

For analysis of perceived lifestyle discrepancy, we generated perceived importance scores for items on a Material Style of Life (MSOL) interview. The MSOL was adapted from a tool used to index access to material assets (Liebert et al., 2013; Snodgrass et al., 2006; Sorensen et al., 2005). After interviews with key informants, we generated a list of 12 items representative of a 'sufficient lifestyle' on Utila. The list includes car/truck, scooter/golf cart, bicycle, television, cellular phone, washing machine, refrigerator, microwave, computer, boat/dory, fishing gear, and home ownership. This list was designed to capture material possessions ranging from items considered commonplace to those considered luxury possessions. Participants ranked the importance of each item for a sufficient lifestyle from "not at all important," to "very important" on a 5-point Likert scale (Supporting Information Table S2). To create a measure of discrepancy, in which higher ranks indicate more discrepancy, importance ranks were multiplied by −1 if an individual owned an item, or multiplied by +1 if an individual did not own an item, such that each item had a value between −5 (perceiving an item as "very important" and having access to it) and +5 (perceiving the item as "very important" and not having access to it). We then summed across items to create a scale of the perceived importance of material assets, weighted by lack of ownership/access, and scaled the variable to be between 0 and 100. The resulting variable shows the discrepancy between what individuals have and what they feel that they need for a sufficient lifestyle. Higher scores denote greater perceived discrepancy between an individual's current lifestyle and what she or he feels is necessary for a sufficient lifestyle. Lower scores denote having met or exceeded what was perceived as necessary for a sufficient lifestyle.

TABLE 1 Descriptive statistics

	Mean (SD)	
Variable (Range)	**Males**	**Females**
N	18	39
Age (18–70 years)	39.3 (15.0)	39.4 (12.1)
Years of Education (2–20 years)	8.9 (4.8)	9.1 (4.6)
Income Category (0–5)	3 (1.3)	2.5 (1.3)
Occupational Rank (1–3)	2.3 (0.7)	2.2 (0.7)
Perceived Lifestyle Discrepancy (0–100)	33.1 (24.4)	38.1 (15.6)
MacArthur subjective SES (1–8)	4.4 (1.9)	4.4 (1.5)
% Smokers	22.2	7.7
% Mainland Honduran	66.7	79.5
AUC cortisol pg/mL	7336.9 (4292.0)	6967.4 (2526.1)
Collection time 1 cortisol pg/mL	1027.4 (634.6)	1084.3 (571.5)
Collection time 2 cortisol pg/mL	732.1 (577.0)	762.3 (376.2)
Collection time 3 cortisol pg/mL	701.9 (792.7)	552.0 (371.3)
Δ Cortisol T1 – T2 (pg/mL/hour)	−149.3 (280.0)	−138.0 (342.0)
Δ Cortisol T2 – T3 (pg/mL/hour)	−13.6 (115.0)	−39.4 (96.1)

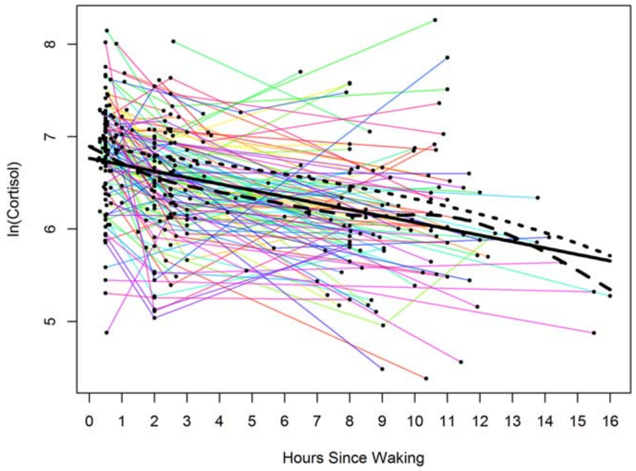

FIGURE 1 Cortisol data collected by hours since waking. Colored lines connect samples from the same day and individual. Solid black lines shows the linear fit to natural log cortisol ($R^2 = 0.17$), dashed black line the fit achieved by a non-linear spline ($R^2 = 0.186$), and the dotted line the fit from a linear decline on non-logged values ($R^2 = 0.09$)

2.4.2 | MacArthur ladder: Perceived social position

The MacArthur scale of subjective SES was developed by the MacArthur Network on SES and Health to capture individuals' sense of their place on the social ladder taking into account standing on multiple dimensions of SES and social position (http://www.macses.ucsf.edu/research/psychosocial/subjective.php). The MacArthur ladder we used consisted of eight rungs, and individuals were asked to imagine that the individual on the top rung is the best off—with the best job, with the most respect in the community, and the most money; while the person on the bottom rung has the lowest standing on these traits. Participants reported the rung that they felt best represented their own standing relative to others on the island. Low scores indicate a perception of low social position, and high scores indicate a perception of high social position.

2.4.3 | Determinants of subjective SES

The variables studied as potential determinants of subjective SES were chosen to reflect aspects of an individual's past and current environment that might impact perceptions of current SES. Individuals were asked demographic questions (age, whether they immigrated or were born on the island, and when they arrived), household questions (household size, number of living children), residential neighborhood location (swamp, inland non-swamp, coastal), type of sanitation ("Bathroom in the house," "Private bathroom outside the house," "Shared bathroom outside the house," "Does the bathroom have running water?"), questions to assess food security ("Do you worry about not having enough food to feed you and your family?"; "Has there ever been a point in your life that you worried about not having enough food to feed you and your family?") and financial security ("Do you have any savings or money put aside for emergencies?"; "Do you owe anyone money?"; "Have you borrowed money from anyone in the last year?"; "Have you loaned money to anyone in the last year?"). An additional variable for 'working in tourism' was created based on their occupation and whether a substantial amount of their income was based on tourism (e.g., clothes launderers, house cleaners, restaurant workers, and bar owners rely primarily on tourism for their income and interact with tourists frequently; whereas tourist-based income and interaction is much more limited for construction workers and nurses). 'Sanitation' was coded as a six-level variable that reflects an individual's household bathroom facilities, ranked from low to high access to proper sanitation: (1) shared, outside, no flush; (2) shared, outside, flush; (3) private, outside, no flush; (4) private, outside, flush; (5) inside, no flush; (6) inside, flush.

2.5 | Salivary cortisol collection

Individuals were followed for two-day saliva collection to help account for diurnal cortisol variation. Three saliva samples per day for two consecutive days were collected at approximately (i) 30 minutes, (ii) 2 hours, and (iii) 8 hours post-waking (Adam & Kumari, 2009). Saliva was collected by the passive drool technique into 2.0 mL Nalgene cryovials (ThermoScientific, USA) and stored within 12 hours in a −20°C freezer until the end of the field season (maximum 3 months). For four participants, samples were collected by the participants and returned to the researchers along with a log of collection and waking times. For the remaining 57 participants, samples were collected by the researcher. The researcher would arrive at the participant's house within 30 minutes of the participant's reported usual wake time to collect the post-waking sample and note the exact wake time and collection time. The researcher would then return twice more, at the designated times, to collect the remaining samples for the day. If the participant woke early, they were asked to call the researcher immediately upon waking so the researcher could come to the participant's house to collect the sample (travel time on the island does not exceed 20 minutes to any location). Due to logistical complications, samples two and three were not always collected exactly at the target times. Mean and standard deviation of collection times for samples 1–3 were (i) 0.56 ± 0.18 hours, (ii) 2.50 ± 0.78 hours, and (iii) 9.6 ± 2.08 hours after waking. Actual collection times and values are shown in Figure 1. Most individuals ($n = 57$) provided all six samples, with three individuals providing only five of the six, and one individual providing only four of the six.

2.6 | Control variables for cortisol

Hormonal birth control use, sleep quality, and frequency of smoking were recorded as controls, given their documented influence on cortisol levels (Badrick, Kirschbaum, & Kumari, 2007; Bouma, Riese, Ormel, Verhulst, & Oldehinkel, 2009; Lange, Dimitrov, & Born, 2010; Meulenberg, Ross, Swinkels, & Benraad, 1987; Wilkins et al., 1982). Hormonal birth control was recorded as use of hormonal birth control shot (Depo-Provera), oral contraceptive, or birth control implant (Implanon or Nexplanon). No women had intra-uterine devices. Hours of sleep were recorded and followed up with "What is the quality of your sleep?" Hours of sleep was entered into models as a continuous variable, and sleep quality was first transformed into a factor variable with four levels: "I don't sleep well", "I wake up more than once a night", "Sometimes I wake up once a night", "I sleep well", and then converted to a continuous variable for analyses. Original models used hours of sleep to adjust for effects of sleep, then were followed up with both variables entered together. For smoking, participants were asked: "Do you currently smoke cigarettes?" Followed up by: "If no, did you ever smoke cigarettes?" Responses were coded as 0 for 'never smoked,' 1 for 'ex-smoker,' and 2 for 'current smoker' (Badrick et al., 2007). Although BMI was recorded, it was not used as a control in this study due to conflicting studies on the influence and directionality of its relationship with cortisol (Rask et al., 2001; Veen et al., 2009).

2.7 | Laboratory analysis

Samples were transported on dry ice to the U.S. and kept at −80°C in the UCSB Human Biodemography Lab until analysis (4–6 months). Samples were thawed and centrifuged at 1500*g* for 20 minutes, and the aqueous layer assayed in duplicate using an enzyme immunoassay utilizing C. Munro's R4866 anti-cortisol antibody (Munro & Stabenfeldt, 1985; Trumble, Brindle, Kupsik, & O'connor, 2010). The limits of detection for this assay are 78.125 pg/mL to 10,000 pg/mL (Munro & Stabenfeldt, 1985). The within and between assay CVs for cortisol ($n = 11$ plates) were 4.29% and 6.20% for the high (1044.5 pg/ml), and 8.17% and 8.00% for the low (271.4 pg/ml) in-house controls, respectively.

2.8 | Participant exclusions

Four individuals were excluded from analysis: one because cortisol in all of the individual's samples was below assay detection limits, likely indicating contamination or an error in collection; a second was excluded due to the observation of blood (red color) in the samples (Kivlighan et al., 2004); a third was omitted due to prescription Metformin use, a medication used to treat diabetes that alters glucose production (Champaneri et al., 2013). The fourth individual provided only four samples, and was not included in the study, due to an inability to estimate slope over two days. Our final sample includes 57 individuals.

2.9 | Statistical analyses

2.9.1 | Diurnal cortisol modeling

All modeling was done using collection times relative to waking, since the collection times themselves were not always exact. In modeling diurnal change, cortisol values were natural log transformed before analysis due to skewed distributions and because a log-linear model fit the pattern of cortisol decline across the day better than a linear model (Figure 1). Parameters of the diurnal change in log cortisol were modeled simultaneously in linear mixed models with random effects for individual and day of collection (nested within individual) (Hruschka, Kohrt, & Worthman, 2005). The model takes the form:

$$\ln(\mathrm{CORT})_{\mathrm{ijk}} = \beta_0 + \beta_1 T_{\mathrm{ijk}} + b_{0\mathrm{i}} + b_{1\mathrm{i}} T_{\mathrm{ijk}} + b_{\mathrm{ik}} + \varepsilon_{\mathrm{ijk}}$$

The model considers the *j*th measurement for each individual, *i*, on each day, *k*, at time T_{ijk}. β_0, and β_1 measure the population level intercept and slope of diurnal cortisol with respect to time since waking, T_{ijk}. $b_{0\mathrm{i}}$, and b_{ik} are random intercepts for individual and day (nested within individual), and the random slope for individual $b_{1\mathrm{i}}$. For all models, our *a priori* expectation was that random effects for individual intercept and slope would be required to control for non-independence of samples and to allow for subsequent modeling of area under the curve (see below). To verify within individual covariance and confirm that mixed models should be used, we first calculated unconditional intra-class correlations (ICCs) using *ICCest* in the *ICC* package (Wolak, Fairbairn, & Paulsen, 2012), followed by estimating conditional ICCs by comparing the variance attributable to random effects (*VarCorr* in *nlme*) as a proportion of the total variance in *lme* models, controlling for collection time (Pinheiro & Bates, 2000). Mixed models were run with *lme* in the *nlme* package in R 3.0.2 (R Core Team, 2013).

2.9.2 | Estimation of area under the curve

We calculated mean cortisol AUC with respect to ground for each individual. AUC was calculated by integrating the area under the diurnal cortisol function for each person, *i*, between 30 minutes and 11.5 hours after waking, using the fixed and per individual random intercepts and slopes from the model above:

$$\mathrm{AUC}_{g_i} = \int_{0.5}^{11.5} e^{\beta_0 + b_{0_i} + (\beta_1 + b_{1_i})x} dx$$

Since we integrate using a single mean intercept & slope for each individual, a single AUC for each person, rather than a separate value for each day was calculated. Integration was done with the *integrate* function in R 3.0.2 (R Core Team, 2013). AUC estimated in this way is highly correlated with AUC calculated segmentally (Pruessner, Hellhammer, Pruessner, & Lupien, 2003; Squires et al., 2012) ($r = 0.89$ for this sample), but unlike segmental estimation, controls for variance in sampling times by estimating over a predetermined period with a continuous function. Note that we chose to integrate over 11 hours as this better represents the actual range of collection times, but the choice of integration period makes little difference for this dataset: AUC integrated over 8 hours correlates highly with AUC integrated over 11 hours ($r = 0.999$).

2.9.3 | Missing data

Some data were missing for MSOL items, objective SES, sanitation score, and food security, due to slight inconsistencies across interviews as a result of time constraints or interviewer oversight. Less than 8% of the data were missing for any single variable (Supporting Information Table S1). Missing data points were imputed using multivariate imputation by chained equations (MICE). Dealing with missing data by multiple imputations, as opposed to single imputations, accounts for statistical uncertainty in the imputations (Azur, Stuart, Frangakis, & Leaf, 2011). Regressions were run using 1000 iteration models. Model outputs in the results were generated through pooling of model outputs in R (package: `mice`) (van Buuren & Groothuis-Oudshoorn, 2011). The sample was limited to individuals for whom at least five saliva samples over two days were available; no cortisol data were imputed. There were no differences in conclusions between using complete case analysis versus data with multiple imputations.

2.9.4 | Analysis of covariates

For analyses, we ran two types of models to examine both slope of diurnal decline and AUC. The first series of models examined effects on the slope term in the above mixed models, by adding covariates with both a main effect and an interaction with time since waking term in the form:

$$\ln(\mathrm{CORT})_{ijk} = \beta_0 + \beta_1 T_{ijk} + \beta_2 X_{2i} + \beta_{2s} X_{2i} T_{ijk} + \ \dots \\ + \beta_n + \beta_{ns} X_{ni} T_{ijk} + b_{0i} + b_{1i} T_{ijk} + b_{ik} + \varepsilon_{ijk}$$

$\beta_2 \dots \beta_n$ model the intercept respect to time since waking associated with covariates $X_2 \dots X_\mathrm{n}$ and $\beta_{2s} \dots \beta_{ns}$ model changes in the slope of decline with time. For simplicity, we report only the slope terms from these models in our results section below, since the interpretation of the intercept parameters depends entirely on when the time variable is centered. Effects on overall cortisol level are therefore more clearly captured with an analysis of AUC.

Thus, in the second set of models, we used generalized linear models to examine the effects of covariates on AUC. Since we integrated only one average AUC per person, random effects were not needed for these models.

With each type of model, first a series of base models were run to evaluate independent associations between objective and subjective measures of SES on slope/AUC cortisol, controlling for age and sex. Second, to determine whether objective or subjective SES variables were independent predictors we ran subsequent models with both types of predictors. In models assessing the relationship between objective SES and cortisol, dummy variables denoting presence or absence of remittances sent and/or received were also used as controls; however, because remittance controls were not significant in any model, they were removed from final analyses. Initial models also controlled for immigration status, but this control was also omitted from final analysis because it showed no effect. Similarly, we also found no significant effects of birth control use, hours or quality of sleep, or smoking on cortisol, so omitted these controls from further analyses. All variables were checked for multicollinearity using the variance inflation factor (VIF) since subjective and objective SES measures were all moderately correlated with one another. VIF values were all below two, indicating no evidence of problematic collinearity (Zurr, Ieno, & Elphick, 2010).

Finally, to examine predictors of subjective SES, we used generalized linear models that included all variables hypothesized to influence subjective SES, which included: age, sex, immigration to the island (yes/no), neighborhood, household size, number of living children, lifetime food scarcity (yes/no), current food scarcity (yes/no), sanitation, money owed to others (yes/no), money borrowed in last year (yes/no), money lent in last year (yes/no), emergency savings (yes/no), and working in tourism (yes/no). We then used the stepAIC function in R (package: `MASS`) to determine the best-fit model for predicting subjective SES, established by the model with the lowest AIC (Akaike information criterion) (Venables & Ripley, 2002). We then included subjective SES measures in the models to assess the mediation effects of subjective SES between each variable and cortisol, and tested whether the variables predicted cortisol independently.

In models, all predictors were standardized; cortisol was logged, but not standardized. As such, all reported values in models are unstandardized betas in units of logged cortisol (for AUC) or change in logged cortisol per hour (for slope), unless otherwise noted.

3 | RESULTS

Demographic descriptive statistics are reported in Table 1. The mean age of individuals in the sample was 39 ± 15.2 years, and 75% of the sample was from the Honduran mainland. On average, individuals had 9.0 ± 4.3 years of education, earned 5–10,000 Lempira per month, and had a mean occupational rank of 2.3 ± 0.6. Mean perceived lifestyle discrepancy, which was measured on a scale of 0–100, was normally distributed with a mean of 36.6 ± 18.7. Individuals' mean placement on the MacArthur ladder was 4.4 ± 1.9, with no differences by sex ($t = -0.13$, $P = .89$). Interestingly, though the components of the objective SES measure did not differ by sex, women reported greater perceived discrepancy than men ($t = -2.96$, $P = .007$). While mainland immigrants ("Hondurans") did not significantly differ from non-immigrants ("Utilians") in regards to their years of education ($t = 0.34$, $P = .73$), income ($t = 0.18$, $P = .86$), or occupational prestige ($t = -0.65$, $P = .52$), Hondurans had significantly fewer material assets ($t = -3.36$, $P = .003$) and perceived greater lifestyle discrepancy compared to Utilians ($t = 2.62$, $P = .02$; Supporting Information Table S3). Utila-born participants were on average older than Hondurans, likely as a result of smaller Utilian sample size and because the project was conducted out of a health center frequented mainly by Hondurans. Due to sample size constraints, these groups were not analyzed separately; however, as mentioned above, immigration status was added as a control in initial models, but was removed from final models due to lack of effect.

3.1 | Consistency of individual differences in diurnal cortisol patterns

To determine the proportion of variance in cortisol levels attributable to differences between individuals and to verify the appropriateness of using mixed models, we first determined the variance in log cortisol levels attributable to individual identity. For each sampling time we estimated unconditional intraclass correlations (ICCs). ICC values suggested considerable within individual correlation: for sample 1, ICC = 0.42, CI = 0.19–0.61; sample 2, ICC = 0.60, CI = 0.40–0.74; and sample 3, ICC = 0.54, CI = 0.32–0.70. To verify this consistency, we also examined correlations between cortisol values on the same individual during the same sampling period, controlling for exact time since waking. This analysis yielded similar results, supporting the use of mixed models (Supporting Information Figure S1). Finally, we examined the variance attributable to random effects at the individual and day of collection (nested by individual) levels, controlling for time of collection. From this base model, the variance attributable to individual identity represented 49.7% of the total variance, with 50.2% residual variance. Less than 0.1% of the variance was attributable to samples on the same individual having been collected on the same day. Taken together, these results suggest that individuals have similar cortisol values at similar times of day across days, but that measures within a day do not necessarily deviate together. That is, a single elevated measure on a particular day is not predictive of an elevation in other samples for that individual on the same day.

3.2 | Correlations among objective and subjective SES measures

Objective SES was negatively correlated with perceived lifestyle discrepancy ($r = -0.56$, $P < .001$), and positively with perceived social status ($r = 0.29$, $P = .03$). Perceived lifestyle discrepancy was negatively correlated with perceived social status ($r = -0.46$, $P = .002$).

3.3 | Prediction one: Both objective and subjective SES will predict cortisol parameters

Models comparing objective and subjective SES and their associations with cortisol slope and AUC are reported in Table 2 (for associations with individual time points, see Supporting Information Table S4). Note that negative values for slope denote steeper slopes, since negative slopes represent decline during the day, while positive values for slope denote a slope that declines less, that is a slope that would be described as blunted or flattened. Controlling for age and sex, objective SES was associated with a steeper slope, trending toward significance ($\beta = -0.02$ log cortisol per hour, $P = .06$), but unrelated to AUC cortisol ($\beta = -0.09$ log cortisol, $P = .59$). Because objective SES is a composite measure, we also ran models using each subcomponent of objective SES (occupational rank, educational attainment, and income). Of these, occupational rank was associated with a steeper slope ($\beta = -0.028$, $P = .003$).

Perceptions of high lifestyle discrepancy (i.e., greater perceptions of unmet needs) significantly predicted a blunted slope and higher AUC cortisol ($\beta = 0.030$, $P = .003$, and $\beta = 0.290$, $P = .04$, respectively; Figure 2). These findings were primarily driven by the effect of perceived lifestyle discrepancy on higher late afternoon cortisol ($\beta = 0.232$, $P = .07$; Supporting Information Table S4). Perceived social status did not associate with any measure of HPA function (Table 2).

3.4 | Prediction two: Subjective SES predicts cortisol beyond objective SES

To further evaluate the relationship between perceived lifestyle discrepancy and cortisol, we ran models that controlled for age, sex, and objective SES (Table 2). In these models,

TABLE 2 Comparison of objective and subjective measures of SES

		Objective SES		Perceived Discrepancy		Perceived Social Status		Age		Sex	
Dependent	Model	β	*P*	β	*P*	*B*	*P*	β	*P*	β	*P*
AUC_g	1	−0.090	.592	-	-	-	-	0.014	.193	0.135	.647
	2	-	-	**0.290**	**.036**	-	-	0.007	.523	0.069	.820
	3	-	-	-	-	−0.059	.695	0.017	.154	0.119	.684
	4	0.007	.975	0.293	.091	-	-	0.007	.533	0.069	.824
	5	−0.075	.676	-	-	−0.036	.828	0.015	.210	0.132	.656
Slope	1	−0.021	.061	-	-	-	-	0.000	.649	0.035	.066
	2	-	-	**0.030**	**.003**	-	-	0.001	.289	**0.048**	**.024**
	3	-	-	-	-	−0.006	.518	0.001	.362	0.032	.100
	4	−0.001	.936	**0.029**	**.025**	-	-	0.001	.309	**0.048**	**.025**
	5	−0.022	.077	-	-	0.002	.836	0.000	.730	0.035	.067

Parameter estimates are unstandardized betas. Predictor variables were standardized; however, cortisol was logged, but not standardized. Significant effects are bolded. Parameters for AUC_g models refer to the main effects of the given variables in a generalized linear model. Parameters for Slope refer to the interaction term between the given variable and the effect of time since waking on log cortisol in linear mixed models with random effects for participant and collection on the same day. Note that the main effects for the slope models are not shown, since the interpretation of these effects is dependent on how the time since waking variable is centered.

the relationship between objective SES and slope steepness was significantly reduced once perceived discrepancy was added to the model ($\beta = -0.002$, $P = .94$). Similarly, the relationship between occupational rank and cortisol slope disappeared once perceived lifestyle discrepancy was included in the model (See Supporting Information Table S5).

Controlling for age, sex, and objective SES, perceived discrepancy remained a significant predictor of blunted slope ($\beta = 0.029$, $P = .03$). Sex was also a significant predictor in this model with men having more blunted slopes than women ($\beta = 0.048$, $P = .025$). However, the relationship between perceived lifestyle discrepancy and cortisol slope did not differ between men and women (β_{sex}*discrepancy= 0.027, $P = .118$). For AUC, though controlling for objective SES diminished the statistical significance of the perceived discrepancy effect on AUC, it did not reduce the magnitude of the effect ($\beta = 0.293$, $P = .091$). Perceived social position did not associate with cortisol outcomes, regardless of the inclusion of objective SES.

3.5 | Determinants of lifestyle discrepancy

Because perceived lifestyle discrepancy had the strongest and most reliable effect on measures of cortisol, we explored social, economic and ecological factors that we hypothesized might affect perceptions of discrepancy. Using stepwise AIC model selection to determine the best-fit model, the variables retained as the best predictors of perceived lifestyle discrepancy were objective SES, sanitation, immigration status, owing money, and lifetime food scarcity (Table 3). All other variables fell out of the final model (for correlations, see Supporting Information Table S6). Being an immigrant from the mainland significantly predicted higher perceived lifestyle discrepancy ($\beta = 0.316$, $P = .002$). Owing money predicted lower discrepancy ($\beta = -0.206$, $P = .032$). Having experienced food scarcity over the life course was associated with lower lifestyle discrepancy ($\beta = -0.303$, $P = .005$). Apart from objective SES ($\beta = -0.755$, $P < .001$), access to sanitation was the most significant predictor of perceived

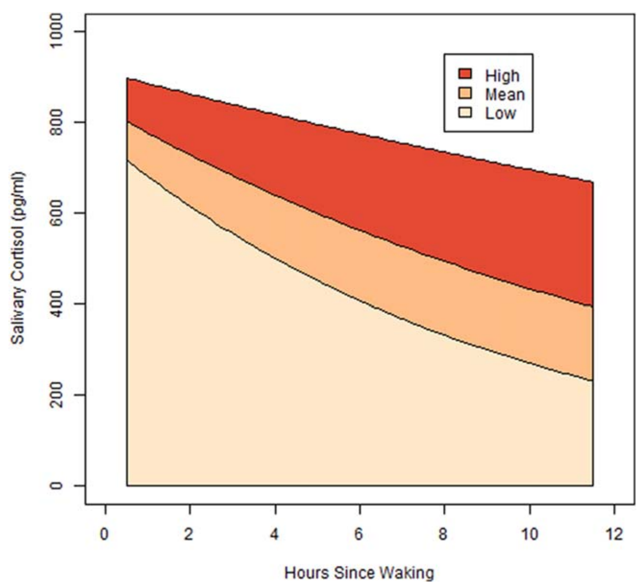

FIGURE 2 Relationship between lifestyle discrepancy and cortisol. Values are predicted from model 4 in table 2 and control for age, sex, and objective SES. High, mean, and low discrepancy represent −2, 0, and +2 standard deviations in the standardized discrepancy measure. Individuals with high discrepancy (not meeting their perceived needs), have a significantly blunted diurnal slope, and higher AUC, compared to those who have met or exceeded what they feel is necessary for a sufficient lifestyle

TABLE 3 GLM analysis of perceived lifestyle discrepancy

Variable	β	SE	*t*-ratio	*P* value
Immigrated from mainland	0.316	0.096	3.302	.002
Owes money	−0.206	0.093	−2.218	.032
Lifetime Food Scarcity	−0.303	0.102	−2.980	.005
Sanitation	−0.348	0.103	−3.386	.002
Objective SES	−0.755	0.137	−5.492	<.001
Age	−0.011	0.008	−1.480	.146

Note: Variables shown are those retained in the final model (stepAIC) as best predictors of perceived lifestyle discrepancy. Variables dropped from the model: sex, emergency savings, money borrowed, money lent, neighborhood, household size, number of children, working in tourism, current food scarcity.

lifestyle discrepancy, with poor access to sanitation predicting higher perceptions of discrepancy ($\beta = -0.348$, $P = .002$).

3.6 | Lifestyle discrepancy as a mediator between environment and cortisol

Owing money and access to sanitation were the only determinants that had direct effects on cortisol (Figure 3). Owing money was independently associated with slope steepness ($\beta = -0.022$, $P = .024$). Better sanitation was independently associated with lower AUC cortisol ($\beta = -0.540$, $P < .001$). Once perceived lifestyle discrepancy was included in the model, owing money continued to be significantly associated with slope steepness ($\beta = -0.021$, $P = .046$), and sanitation continued to be significantly associated with AUC ($\beta = -0.519$, $P = .002$). Interestingly, the parameters for owing money and sanitation remain nearly unchanged, suggesting that perceived lifestyle discrepancy does not mediate the direct effects of these variables on cortisol. None of the other determinants considered as predictors of lifestyle discrepancy were directly related to cortisol and as such were not tested for mediation through perceived lifestyle discrepancy.

4 | DISCUSSION

In this study, we investigated whether objective and subjective SES were predictors of HPA function among residents on Utila, as measured by diurnal decline and cumulative daily exposure (AUC) in salivary cortisol. We found that higher perceived lifestyle discrepancy predicted blunting of the diurnal cortisol slope. When included in the same model, the effect of objective SES was greatly reduced while perceived lifestyle discrepancy remained a significant predictor of a blunted cortisol decline and AUC, suggesting that the effects of objective SES are largely mediated by perceived lifestyle discrepancy. These patterns were primarily explained by higher late afternoon cortisol rather than lower morning levels.

Our findings parallel similar studies addressing dimensions of subjective SES related to diurnal salivary cortisol (Agbedia et al., 2011; Squires et al., 2012), and may give further insight into the relationship between subjective SES and dimensions of cortisol. Under healthy HPA functioning, when cortisol concentrations are at an appropriate level, cortisol exerts a feedback signal on receptors in the hippocampus, hypothalamus, and pituitary gland, which suppresses its further release (Jarcho et al., 2013). The relatively flatter diurnal cortisol rhythm and higher AUC in individuals with higher perceived lifestyle discrepancy suggests a failure in the negative feedback system—an effect referred to as "glucocorticoid resistance", which has been linked to posttraumatic stress disorder, fatigue, and depression, among other psychological conditions associated with socioeconomic adversity (Jarcho et al., 2013; Weinrib et al., 2010; Yehuda, Golier, Yang, & Tischler, 2004).

The relationship between perceived lifestyle discrepancy and HPA function offers support for the hypothesis that individuals use social information to determine appropriate baselines for sufficient resources (Hymen, 1942; Kondo, 2012; Mullainathan & Shafir, 2013). Exposure to luxury and

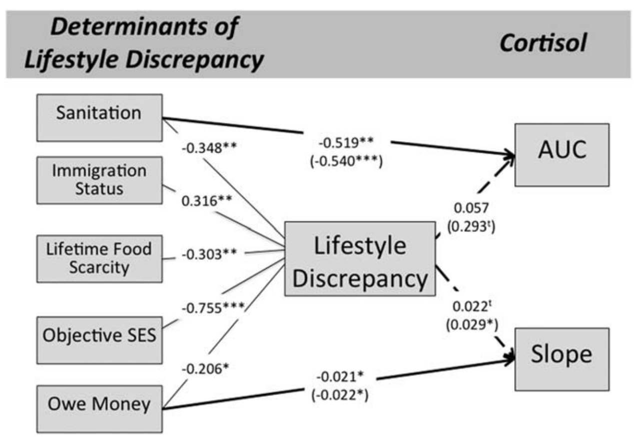

FIGURE 3 Determinants of lifestyle discrepancy and their direct and indirect relationships with cortisol. Solid thin lines show the relationship between socio-environmental and ecological factors and lifestyle discrepancy; the variables shown are those that were retained as the best predictors of lifestyle discrepancy (see Table 3). Sanitation and owing money were the only predictors of lifestyle discrepancy that also had direct effects on parameters of cortisol. Solid thick lines show the relationship between sanitation and owing money on parameters of cortisol, as mediated through lifestyle discrepancy. Dashed lines show adjusted relationship between lifestyle discrepancy and cortisol, after controlling for sanitation or owing money. Numbers in parentheses are direct, unmediated, effects of the variables on their respective measure of cortisol. Significance demarcations are: ᵗ($P < .1$), * ($P < .05$), **($P < .01$), ***($P < .001$)

disposable income on Utila is ubiquitous. However, there is striking variation in individuals' interest in economic advancement and cultural assimilation. Some Utilians participate in the tourist economy as a means of subsistence, but spend the rest of their time in more traditional activities, like farming and fishing; others attempt to immerse themselves in the tourist culture working at dive shops and spending time living the tourist "vacation lifestyle." Similarly, some Hondurans attempt to integrate themselves into the larger island lifestyle, whereas others retain strong connections with families on the mainland and show little interest in assimilating to either Utilian or tourist culture. Ultimately, the composition of one's personal reference group likely plays an important role in understanding variation in perceptions, salience of social information, and impacts on HPA functioning. One caveat is that higher cortisol in the evening could be due to differences in sleep patterns associated with employment - some individuals collect crabs from the bush at night or work extremely late shifts in other jobs such as taxi drivers or cooks. While self-reported hours and quality of sleep did not show an effect, the cumulative effect of hours, quality, and timing of sleep may have an unmeasured effect.

Use of social information may be intertwined with status in that social acumen likely bolsters one's ability to gain status (von Rueden, Gurven, & Kaplan, 2011). The absence of a relationship between perceived status and HPA function could be due to a number of factors. Though the scale was correlated with objective SES, the magnitude of correlation was relatively weak ($r = 0.29$). Further, the correlation was driven by only a few people on the very high and very low end of objective SES while for the middle 80% of the sample there is no relationship (Supporting Information Figure S2). Utila is a small island with both a strong sense of community and fierce in- versus out-group dynamics. One possibility is a response bias in the use of the MacArthur scale whereby even objectively better-off individuals tended to place themselves in the middle of the ladder, stating they were "no better than anyone else" or "they didn't really have much." Another possibility is that individuals were confused by the hypothetical nature of the scale itself, and responses could reflect how they think others would view their social status-which might not matter insofar as they are content with their current lifestyle. The perceived lifestyle discrepancy measure may not suffer from these issues, because individuals are not explicitly asked to state how discrepant their lifestyle is from their ideal (which can lead to response biases like negative affect). Thus, perceived lifestyle discrepancy may represent a more 'objective' way to understand an individual's 'subjective' experience.

Consistent with other studies that have found that immigrants tend to have lower subjective SES than non-immigrants, we found immigration status to be significantly associated with perceived lifestyle discrepancy (cf: Gong, Xu, & Takeuchi, 2012). Immigration status likely influences perceptions through differential access to social and economic resource opportunities. Social networks and support may buffer perceptions of threat that stimulate the HPA axis; however, migrants often enter into an area with few social ties, and successfully rebuilding long-term social networks is variable. The social networks that do exist may be more resource-poor, which could translate into decreased acquisition and borrowing power. Hondurans also migrate to the island seeking increased job opportunity and upward mobility, but often experience discrimination and few prospects for mobility. However, immigration status did not have a direct effect on cortisol, suggesting that, in our sample, there was no direct link between being an immigrant and provoking a stress response. That being said, the lack of association may also be due to the relatively smaller sample size of Utilian-born participants.

The association between not owing money and greater lifestyle discrepancy might seem puzzling; however, one interpretation is that the ability to regularly borrow (and thus owe) money indicates having established relationships with individuals who are better off than you. Not owing money may instead reflect a lack of credit, a compromised social network, and greater absolute deprivation and access to resources, including those more readily accessible through borrowing. This corresponds with other studies that have found evidence of greater psychosocial stress resulting from compromised social networks and perceived lack of available interpersonal resources (Cohen & Wills, 1985; Lueck & Wilson, 2010), and is further substantiated by the fact that not owing money was directly associated with cortisol slope, even after controlling for the mediation effects of perceived discrepancy.

The most influential predictor of perceived lifestyle discrepancy was lack of access to improved sanitation. Access to sanitation could be related to subjective SES and cortisol in two distinct ways. First, sanitation is one of the most basic elements of human physiological needs (Maslow, 1943) and a number of studies have shown that inadequate or poor sanitation is associated with lower status (Hoelle, 2012; Shuval, Tilden, Perry, & Grosse, 1981; cf: Bhiuya et al., 1986). The implication being that regardless of other material welfare, poor access to sanitation could signal a chronic deprivation of basic human needs that relate to individuals' subjective perceptions of self, and distinctly to their stress levels. Additionally, poor sanitary conditions put individuals at increased exposure to parasites and pathogens. Some research in non-human animals suggests that parasitic and pathogenic infection independently affect HPA function and cortisol (Klar & Sures, 2004; Muehlenbein & Watts, 2010; Stoltze & Buchmann, 2001). This could explain why sanitation had a significant relationship with cortisol, and concordantly, why the relationship between perceived lifestyle discrepancy and cortisol diminished once sanitation was included in the model. However, no similar studies have been done in humans, nor measuring salivary cortisol, specifically. To advance our understanding of the relationship between parasites and HPA function, studies focusing on the relationship between variation in parasite and pathogen exposure and cortisol in humans are needed.

4.1 | Limitations

While not measured in this study, another important consideration is how variation in optimal health-promoting or health-risking behaviors like diet and exercise independently impact HPA function (Pepper & Nettle, 2014). Also likely to be important, as suggested above, is the effect of social network and composition of an individual's reference group on perceptions of adequacy as well as coping strategies, which both might impact HPA function. Given our limited social network data, we were unable to unpack these more complex dynamics. More research coupling social network analysis and biomarkers of stress is needed. The logistical challenges of collecting cortisol in a rural field setting confined us to collecting samples over only two days. As a highly sensitive hormone, cortisol can be variable across days and times of day, due to relatively minor perturbations in an individual's environment. Though many studies rely on an equivalent number or fewer (Desantis et al., 2015; Nyberg, 2012; Squires et al., 2012), in order to reliably assess dysregulation of diurnal cortisol and to address the complexities of the HPA axis in response to psychosocial stimuli, longer periods of sampling may be preferable (Nicolson, 2007). However in assessments of ICCs by individual, we found within-individual consistency across days with about half of the variance in samples attributable to individual identity. This suggests that, for our sample, we might not need more than two days to capture adequate between-individual variation. However, this also suggests that since there was some between-day variation, a single day would have been less accurate, and would have required a larger sample to compensate for the loss of measurement accuracy.

A further limitation is that we did not measure the cortisol awakening response, which is typically measured by collecting a sample immediately at waking and another sample ~30 min later. Salivary cortisol increases by 50–160% within the first 30 minutes of waking (Clow, Thorn, Evans, & Hucklebridge, 2004), and typically peaks between 30 and 45 minutes after waking (Hellhammer et al., 2009). Logistical issues and issues with compliance made it difficult to collect samples immediately upon waking. Instead, we focused on capturing the peak in cortisol and measuring its decline. Because there is no agreed upon 'exact' time for taking a sample to catch the peak free salivary cortisol (Clow et al., 2004), and numerous studies that look at CAR use a collection schedule that calculates CAR from 0 minutes to 30 minutes post-waking, we concluded that collecting the first sample at 30 minutes post-waking was appropriate for minimizing confounding issues of variation in cortisol awakening responses (Champaneri et al., 2012; Hajat et al., 2010; Squires et al., 2012). Our sampling managed to target this goal fairly accurately, with the first samples collected at 0.56 ± 0.18 hours after waking. However, because individuals vary in the timing of their cortisol peaks, any error in the time of collection may have an effect on calculation of slope and AUC. Lastly, though we control for contraceptive use, we do not control for where women were in their menstrual cycles, which has been shown to affect bioavailability of cortisol (Kirschbaum et al., 1999; Wilcox et al., 1988).

5 | CONCLUSION

This study provides important preliminary insights into the relationship between subjective SES and cortisol on the island of Utila. Though longitudinal data will facilitate a more thorough understanding, in this cross-sectional analysis we find evidence that perceived lifestyle discrepancy is related to diurnal decline and cumulative daily exposure to salivary cortisol, indicating that elements of the "lived experience" of SES play a role in the relationship between SES and physiological stress. This role of subjective SES may be either more inclusive than, or independent of, objective measures of SES. Subjective SES incorporates current and future potential, based in part on past experiences, and current resource access that may be extended or crippled by aspects of social capital. Social capital and perception of resources vary with population scale, including the size and content of reference groups. In this context, subjective SES may incorporate objective income and assets along with the ability to buffer lack of assets through other forms of capital. In addition, because subjective SES incorporates overall interest in material assets, it may stand apart as a signal of an individual's relative acceptance of his or her own status, independent of objective SES. On Utila, like in many developing areas where economic inequality is growing, shifts in wealth and opportunity can lead to a psychosocial reframing. As the island's tourist industry becomes increasingly insular, Utilians and Hondurans alike struggle to sustainably capitalize on the industry. Assessing how perceptions change relative to an individual's unique desire and potential for mobility, and the pathway by which perception impacts stress and HPA function, is more complex. However, given the established connection between HPA function and chronic diseases, and the growing epidemic of metabolic syndrome in developing regions, understanding how socioeconomic inequality relates to stress and HPA activation, and downstream consequences of morbidity and mortality, is vital.

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AUTHOR CONTRIBUTIONS

Designed the study: Angela R. García, Aaron D. Blackwell, and Michael Gurven
Collected and analyzed the data: Angela R. García and Aaron D. Blackwell
Wrote the manuscript and conducted all laboratory analyses of biological specimens: Angela R. García
Edited the manuscript for intellectual content and provided critical comments on the manuscript: Aaron D. Blackwell and Michael Gurven.

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