Heat exposure and health outcomes in Costa Rican sugarcane harvesters

Jennifer Crowe

Umeå 2014
To Luis and Roberto
And my parents Jim and Marjorie
...with much love and gratitude.
Abstract

Background The remarkably efficient mechanisms of the human body to maintain its core temperature of 37°C can be inadequate when harsh climatic conditions and excessive muscle movement lead to heat stress, dehydration and potential heat illness, ranging from minor symptoms such as fatigue to a potentially fatal heat stroke. Agricultural workers in the tropics are at high risk, which is expected to increase with climate change. Sugarcane harvesting in Costa Rica is largely done by cutting the cane with a machete, by temporary, subcontracted workers who are often migrants and living in poverty. Sugarcane harvesters are known to be affected by an epidemic of chronic kidney disease of non-traditional origin, currently hypothesized to be related to working conditions.

Objectives This work aimed to better understand and document sugarcane harvester exposure to heat and the health consequences of working under such conditions. Specific objectives were to 1) Document working conditions and heat in the Costa Rican sugarcane industry (Paper I); 2) Quantify heat stress exposures faced by sugarcane harvesters in Costa Rica (Paper II); and 3) Quantify the occurrence of heat stress symptoms and abnormal urinary parameters in sugarcane workers in Costa Rica (Papers III and IV).

Methods This study took place over three harvests following a pilot assessment prior to the first harvest. Methods included direct observation, semi-structured interviews with 24 individuals and a participatory workshop with 8 harvesters about heat-related perceptions, exposures and coping strategies during the harvest and non-harvest season (Pilot). Researchers accompanied workers in the field during all three harvests, measured wet bulb globe temperature (WBGT) and conducted direct observation. Heat exposure assessment was conducted by calculating metabolic load, WBGT and corresponding limit values based on international guidelines (NTP and OSHA) (Harvest 1). Self-reported symptom data were collected using orally-administered questionnaires from 106 sugarcane harvesters and 63 non-harvesters from the same company (Harvest 2). Chi-square test and gamma statistic were used to evaluate differences in self-reported symptoms and trends over heat exposure categories. Finally, liquid consumption during the work shift was documented and urinalysis was conducted pre-and post-shift in 48 sugarcane harvesters on three days; differences were assessed with McNemar’s test on paired proportions (Harvest 3).

Results Sugarcane workers in both the harvest and non-harvest seasons are exposed to heat, but particularly during the harvest season. Field workers have to carry their own water to the field and often have no access to shade. Some plant
workers are also exposed to intense heat. The metabolic load of sugarcane harvesting was determined to be 261 W/m². The corresponding threshold value is 26 °C WBGT, above which workers should decrease work load or take breaks to avoid the risk of heat stress. Harvesters in this study were at risk of heat stress as early as 7:15 am on some mornings and by 9:00 am on all mornings. After 9:15 am, OSHA recommendations would require that harvesters only work at full effort 25% of each hour to avoid heat stress.

Heat and dehydration symptoms at least once per week were experienced significantly more frequently among harvesters than non-harvesters (p<0.05): headache, tachycardia, fever, nausea, difficulty breathing, dizziness, and dysuria. Percentages of workers reporting heat and dehydration-related symptoms increased over increasing heat exposure categories. Total liquid consumed ranged from 1 to 9 L and differed over days (median 5.0, 4.0 and 3.25 on days 1, 2 and 3 respectively). On these same days, the two principle indicators of dehydration: high USG (≥1.025) and low pH (≤5), changed significantly from pre to post-shift (p=0.000 and p=0.012).

Proportions of workers with proteinuria >30 mg/dL, and blood, leucocytes and casts in urine were also significantly different between pre and post-shift samples at the group level, but unlike USG and pH, these alterations were more frequent in the pre-shift sample. 85% of workers presented with proteinuria at least once and 52% had at least one post-shift USG indicative of dehydration.

**Conclusion** Heat exposure is an important occupational health risk for sugarcane workers according to international standards. A large percentage of harvesters experience symptoms consistent with heat exhaustion throughout the harvest season. Pre and post-shift urine samples demonstrate dehydration and other abnormal findings. The results of this study demonstrate an urgent need to improve working conditions for sugarcane harvesters both under current conditions and in adaptation plans for future climate change.

**Key words:** Agricultural worker, Central America, Chronic kidney disease, Climate change, Dehydration, Heat, Heat illness, Heat stress, Sugarcane, Urinalysis, Worker health
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### Abbreviations

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<tr>
<td>ACGIH</td>
<td>American Conference of Governmental Industrial Hygienists</td>
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<td>CDC</td>
<td>Centers for Disease Control and Prevention (USA)</td>
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<tr>
<td>COMISCA</td>
<td>Consejo de Ministros de Salud de Centroamérica y la Dominica Republicana (Board of Ministers of Health from Central America and the Dominican Republic)</td>
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<tr>
<td>CKD</td>
<td>Chronic kidney disease; Includes CKDnT (defined below) and other chronic kidney diseases.</td>
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<tr>
<td>CKDu</td>
<td>Chronic kidney disease of unknown origin (or unknown etiology); Also known as chronic kidney disease of non-traditional etiology (CKDnT)</td>
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<tr>
<td>CKDnT</td>
<td>Chronic kidney disease of non-traditional origin (or non-traditional etiology); Also known as chronic kidney disease of non-traditional etiology (CKDnT)</td>
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<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
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<td>Hothaps</td>
<td>High occupational temperature health and productivity suppression. Hothaps is a “multi-centre health research and prevention programme aimed at quantifying the extent to which working people are affected by, or adapt to, heat exposure while working, and how global heating during climate change may increase such effects.” (1)</td>
</tr>
<tr>
<td>Hr</td>
<td>Hour</td>
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<tr>
<td>ILO</td>
<td>International Labor Organization</td>
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<tr>
<td>IMN</td>
<td>Instituto Metereológica Nacional (Costa Rican Meteorological Institute)</td>
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<tr>
<td>INSHT</td>
<td>Instituto Nacional de Seguridad e Higiene en el Trabajo (National Institute for Workplace Safety and Hygiene) (Spain)</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
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<tr>
<td>ISO</td>
<td>International Organization for Standards</td>
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<tr>
<td>Km</td>
<td>Kilometer</td>
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<tr>
<td>L</td>
<td>Liter</td>
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<tr>
<td>M</td>
<td>Meter</td>
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<tr>
<td>NSAIDs</td>
<td>Non-steroidal anti-inflammatory drugs</td>
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<tr>
<td>NATA</td>
<td>National Athletic Trainers’ Association (USA)</td>
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<tr>
<td>NIOSH</td>
<td>National Institute for Occupational Safety and Health (USA)</td>
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<tr>
<td>NTP</td>
<td>Notas Técnicas en Prevención (Technical Prevention Notes) (Spain)</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupational Safety and Health Administration (USA)</td>
</tr>
<tr>
<td>PAHO</td>
<td>Pan American Health Organization</td>
</tr>
<tr>
<td>PHEL</td>
<td>Physiological Heat Exposure Limit (U.S. Navy)</td>
</tr>
<tr>
<td>SALTRA</td>
<td>Programa Salud, Trabajo y Ambiente en América Central (Program Health Work and Environment in Central America)</td>
</tr>
<tr>
<td>TWL</td>
<td>Thermal Work Limit</td>
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Antecedentes Los extraordinariamente eficientes mecanismos del cuerpo humano para mantener su temperatura basal de 37 °C pueden ser insuficientes cuando condiciones climáticas severas y un movimiento excesivo de los músculos llevan al estrés térmico, a la deshidratación y, en muchos casos, a una enfermedad ocasionada por el calor que puede variar desde síntomas menores como la fatiga hasta un golpe de calor que puede resultar mortal. El riesgo para trabajadores agrícolas es alto, lo cual se prevé que puede aumentar con el cambio climático. En Costa Rica, gran parte de la cosecha (zafra) se realiza cortando la caña de azúcar con machete, en su mayoría por trabajadores temporales y subcontratados, que generalmente son migrantes viviendo en condición de pobreza. Se sabe que los cortadores de caña de azúcar sufren de una epidemia de enfermedad renal crónica de origen no-tradicional, y actualmente existe la hipótesis de que puede estar relacionada con las condiciones de trabajo.

Objetivos Este trabajo tiene el propósito de ayudar a entender mejor y documentar la exposición al calor de los cortadores de caña de azúcar y las consecuencias para la salud de trabajar en esas condiciones. Los objetivos específicos eran: 1) Documentar las condiciones de trabajo y de calor en la industria de la caña de azúcar en Costa Rica (Artículo I); 2) Cuantificar las exposiciones que conducen al estrés térmico que enfrentan los cortadores de caña de azúcar en Costa Rica (Artículo II); y 3) Evaluar la ocurrencia de síntomas de estrés térmico y parámetros urinarios anormales en los trabajadores de la caña de azúcar en Costa Rica (Artículos III y IV).

Métodos Este trabajo se realizó durante tres zafras después de una evaluación piloto realizada antes de la primera zafra. Los métodos incluyeron observación directa, entrevistas semiestructuradas con 24 individuos y un taller participativo con 8 cortadores de caña de azúcar sobre percepciones, exposiciones y estrategias para resistir el calor durante las temporadas de zafra y no zafra (Piloto). Durante las tres zafras, los investigadores acompañaron a los trabajadores en el campo, midieron la temperatura globo bulbo húmedo (TGBH), y con observación directa anotaron las prácticas de trabajo. La evaluación de la exposición al calor se realizó calculando la carga metabólica, la TGBH y los valores límite correspondientes según las normas internacionales (NTP y OSHA) (Zafra 1). Los datos de síntomas reportados fueron recolectados mediante cuestionarios aplicados de forma oral a 106 cortadores de caña de azúcar y 63 personas que trabajan en la misma empresa pero que no realizan dicha labor (Zafra 2). Se utilizaron la prueba Chi-cuadrado y el estadístico Gamma para evaluar las diferencias en los síntomas reportados por el propio individuo y las tendencias en las categorías de exposición al calor. Por último, se documentó el consumo de líquido durante las
jornadas de trabajo y se realizó un análisis de orina antes y después de la jornada en 48 de los cortadores de caña de azúcar durante tres días; las diferencias se evaluaron de acuerdo con la prueba de McNemar para proporciones pareadas (Zafra 3).

**Resultados** Los trabajadores de la caña de azúcar se ven expuestos al calor tanto durante la temporada de zafra como en la temporada de no zafra. Los trabajadores del campo tienen que llevar su propia agua hasta el campo y muchas veces no tienen un lugar con sombra. Algunos de los trabajadores de la planta también se ven expuestos al calor intenso. La carga metabólica del trabajo de cortar caña de azúcar se determinó en $261 \text{ W/m}^2$. El valor límite correspondiente es $26^\circ\text{C TGBH}$, por encima del cual los trabajadores deberían disminuir la carga de trabajo o tomar descansos para evitar el riesgo de estrés térmico. Los cortadores de caña de azúcar en este estudio se vieron en riesgo de sufrir estrés térmico desde las 7:15 a.m. algunas mañanas y a las 9:00 a.m. todas las mañanas. De acuerdo con las recomendaciones de la OSHA, después de las 9:15 a.m. los cortadores deberían trabajar a un esfuerzo máximo solo un 25% de cada hora para evitar el estrés térmico.

Los síntomas del calor y la deshidratación fueron experimentados por lo menos una vez por semana, fueron más frecuentes en cortadores de caña de azúcar a diferencia de quienes no realizaban dicha labor ($p<0.05$): dolor de cabeza, taquicardia, fiebre, náuseas, dificultad para respirar, mareos y disuria. El porcentaje de trabajadores que reportaron síntomas relacionados con el calor y la deshidratación aumentó según las categorías de creciente exposición al calor. El total de líquido consumido fue de 9 L y varió con los días (media proporcional 5.0, 4.0 y 3.25 en los días 1, 2 y 3 respectivamente). En estos mismos días, los dos indicadores principales de la deshidratación: gravedad específica (USG) alta ($\geq 1.025$) y pH bajo ($\leq 5$), cambiaron de forma significativa en las muestras prejornada y posjornada ($p=0.000$ y $p=0.012$).

Las proporciones de los trabajadores con proteinuria $>30$ mg/dL, y sangre, leucocitos y cilindros en la orina también fueron significativamente diferentes entre las muestras tomadas antes y después de la jornada laboral a nivel de grupo pero, a diferencia de la USG y el pH, estas alteraciones no fueron más frecuentes en la muestra prejornada. El 85% de los trabajadores presentó proteinuria al menos una vez y el 52% mostró un USG indicativo de deshidratación al menos en una tarde.

**Conclusión** La exposición al calor representa un riesgo serio en la salud ocupacional de los trabajadores de la caña de azúcar de acuerdo con los estándares internacionales. Un alto porcentaje de los cortadores de caña de azúcar experi-
mentan síntomas consecuentes con el agotamiento por el calor durante la temporada de la zafra. Las muestras de orina antes y después de la jornada de trabajo demuestran deshidratación y otros resultados anormales. Los resultados de este estudio demuestran la urgente necesidad de mejorar las condiciones de trabajo de los cortadores de caña de azúcar tanto en las condiciones actuales como en los planes de adaptación para el cambio climático futuro.

**Palabras clave:** Trabajador agrícola, Centroamérica, Enfermedad renal crónica, Cambio climático, Deshidratación, Calor, Enfermedad ocasionada por el calor, Estrés térmico, Caña de azúcar, Análisis de orina, Salud del trabajador, Zafra
Prologue

In the very early stages of this project, a participatory workshop was held with eight Nicaraguan harvesters. We conversed about their perceptions, feelings and experiences on topics including heat, productivity, health and climate change. When we got close to the end, I asked, “Is there anything else that you think we, the researchers, should know before we start this project?” One of the harvesters raised his hand and said something that I have tried to keep ever-present and which provides context for understanding the results presented here:

“I think you should know that most of us have worked in lots of jobs and I’ll tell you this:
This is the most savage work that exists and it is the lowest paying. Nobody does this job unless they have to.”
List of papers

This thesis is based on the following papers, which are referred to in the text by their Roman numerals:


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## Thesis at a glance

<table>
<thead>
<tr>
<th>Paper</th>
<th>Reference</th>
<th>Methods</th>
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Direct observation  
Exploratory interviews with workers |
WBGT measurements  
Estimation of metabolic load (NTP guidelines) and threshold limits (OSHA) |
Morning and afternoon urinalysis in 48 harvesters on 3 work days  
WBGT measurements |
<table>
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<tr>
<th>Aim</th>
<th>Main Finding</th>
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<tbody>
<tr>
<td>Assess working conditions and heat in the sugarcane industry as a basis for future design.</td>
<td>Workers in the harvest and non-harvest season are exposed to heat. Field workers have to carry their own water to the field and often have no access to shade. Some plant workers are also exposed to intense heat. Research is needed to better understand the factors driving and interacting with heat exposure to protect workers.</td>
</tr>
<tr>
<td>Quantify heat exposure in sugarcane harvesters in Costa Rica</td>
<td>The metabolic load of sugarcane harvesting is approximately $261 \text{ W/m}^2 (6.8 \text{ kcal/min})$, corresponding to a limit value for work at maximum effort of $26^\circ \text{C WBGT}$. Harvesters are at risk for heat stress for the majority of the work shift.</td>
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<tr>
<td>Determine the frequency of self-reported heat-related symptoms among harvesters exposed to heat stress as compared to non-harvesters from the same company.</td>
<td>Heat and dehydration symptoms were experienced more frequently among harvesters. Percentages of workers reporting symptoms increased over increasing heat exposure categories. A large percentage of harvesters experience symptoms of heat exhaustion throughout the harvest season.</td>
</tr>
<tr>
<td>Describe liquid consumption, WBGT, and urinary indicators in pre and post-work shift samples collected during 3 days for 48 sugarcane harvesters.</td>
<td>Sugarcane harvesters demonstrated evidence of dehydration at the end of the shift and renal injury markers in pre-shift samples.</td>
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</table>
Introduction

Almost every human being has felt uncomfortable due to heat while exercising or working. If given a choice, most athletes would prefer to run marathon when the temperature is 25°C instead of 34°C. This is because no matter how physically fit a person is, she will be able to run faster and farther needing less water on the cooler day, especially if there is cloud cover, a slight breeze and low humidity. Most of us would make the same decision picking a day to run a marathon, play a game of ball with our kids, ride a bicycle to work, plant flowers or cut sugarcane. We intuitively know what laboratory tests show: we reach our limit more rapidly under hot, humid conditions (2).

This work grew out of a desire to better understand and document worker exposure to heat and the consequences such work has on health and productivity in the face of climate change. The choice to focus on sugarcane harvesters in Costa Rica is built on previous work done as a part of Program Health Work and Environment in Central America (SALTRA). SALTRA identified sugarcane workers as a priority for research in Costa Rica based on the high-risk nature of the job. As a result, participatory workshops and risk maps were used to identify, prioritize and suggest solutions for workplace risks in two sugarcane companies (“in- genios”) (3). Later, with support from the “High occupational temperature health and productivity suppression” (Hothaps) initiative (1), we began looking into one of the many risks identified in the sugarcane industry: heat exposure.

The papers presented here attempt to demonstrate why heat is an important issue for sugarcane harvesters (Papers I and II) and provide data to aid understanding of heat exposure in sugarcane harvesters (Paper II) and the negative outcomes that they currently experience (Papers III and IV). It is my hope that these data provide a basis for moving towards fair and decent working conditions and improved health for sugarcane harvesters now as well in the context of future climate change.
Background

Cooling the body in hot environments

Although the specific mechanisms of cooling and overheating the human body are complex and involve most of the body’s systems (4), the basic phenomenon is relatively straightforward. Human beings need to maintain a core body temperature of 37°C. Heat can influence the body both externally (i.e. air temperature) and internally because heat is created with muscle movement (exercise) as well as the basic metabolic functions that keep a person alive. When heat from internal and/or external sources threatens to raise the core temperature above 37°C, a number of remarkably efficient mechanisms work together to shed the excess heat through radiation, conduction, convection and evaporation (2,5).

The body’s effectiveness at shedding heat depends to a large degree on four climatic factors: air (dry) temperature, radiant temperature, humidity and air movement (wind)(6). The interaction of the body’s defenses and the climatic factors can be changed by the clothing a person wears. For example, sweating is the body’s most effective method for shedding heat, but works best when there is low humidity, allowing for faster evaporation and when a person is wearing no or lightweight clothing. The efficiency of the body’s defenses can be limited by a number of factors including acclimatization, hydration or underlying health problems and the use of certain medications (2). When the body’s attempts to rid itself of excess heat are inadequate, the next natural mechanism kicks in: the person begins to reduce his physical activity, thereby reducing the heat created by muscle movement.

Heat-related health outcomes

Of major concern for working populations are the different heat illnesses that can result from exposure to heat (often together with dehydration). Names used for each condition vary slightly across different academic disciplines and cultures, but generally, there is a range of severity in the illnesses beginning with relatively common heat cramps to the medical emergency and often fatal heat stroke. However, as stated in the US Army air Force Technical Bulletin, “The diagnostic categories of heat exhaustion, exertional heat illness and heat stroke have overlapping features that should be thought of as different regions on a continuum rather than discrete disorders...” (7). Additionally, victims do not always experience symptoms “in order” or with the same rate of progression – that is, a person can experience heat exhaustion without having first experienced muscle cramps or a person who presents with heatstroke may not have shown clear signs of heat exhaustion hours before reaching a critical condition (5,7).
“Heat illness” is one common term for health outcomes related to heat exposure and it can be helpful to categorize outcomes as “minor heat illness” and “major heat illness.” Minor heat illnesses include edema (swelling in the extremities), syncope (fainting as a result of blood pooling in the extremities) and cramps. Heat exhaustion is more severe and results from cardiac failure to simultaneously meet the demands of thermoregulation and physical activity, but is classified under minor heat illness because no apparent organ damage is present. It often occurs in conjunction with dehydration and symptoms such as fatigue, headache, muscle cramps, weakness, dizziness, nausea, vomiting, tachycardia, hyperventilation, ataxia, malaise, hypotension and transient alteration in mental status (7). Working under heat stress can lead to any of the above outcomes if not properly managed and can also lead to diminished mental capacity (8) and increased accident risk (9). Additionally, heat stress and dehydration both lead to decreased physical work capacity (10).

Major heat illnesses include heat stroke, a medical emergency in which the body’s core temperature remains above 40°C, provoking multiple organ failure, neurological damage, convulsions, unconsciousness and death. Heat stroke in working populations is usually “exertional heatstroke” in which part of the heat that is unsuccessfully dissipated by the body is created by muscle exercise (7), although heat stroke can also happen without muscle-generated heat, as sometimes happens in elderly, sick or otherwise homebound individuals in heatwaves (11). Exertional rhabdomyolysis (breakdown of muscle tissue resulting in the release of proteins and other toxins into the bloodstream), also a major heat illness, may occur with or without manifestations of other heat illnesses (7).

The interconnectedness of the body’s systems means that it is very difficult to separate the effects of heat from the effects of dehydration which often occur in tandem. However, even the very severe outcome of exertional heatstroke can occur in the absence of notable dehydration (12). The basics of heat exposure and health outcomes are presented in Table 1, summarized from the Army-Air Force Technical Bulletin on heat stress control and heat casualty management (7). The reader is directed to the Army-Air Force Bulletin and the National Athletic Trainers’ Association (NATA) Position Statement on Exertional Heat Illness for detailed descriptions of the signs and symptoms of each condition (5).

<table>
<thead>
<tr>
<th>Minor heat illnesses and heat-related conditions</th>
<th>Heat edema</th>
<th>Syncope</th>
<th>Heat cramps</th>
<th>Heat exhaustion</th>
</tr>
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<tbody>
<tr>
<td>Definition</td>
<td>“Swelling and discomfort of the hands and/or feet”</td>
<td>“…a temporary circulatory failure due to pooling of blood in the peripheral veins - especially those of the lower extremity - and a consequent decrease in diastolic filling of the heart” (Also known as “parade syncope”)</td>
<td>“Brief, recurrent, often agonizing skeletal muscle cramps of the limbs and trunk”</td>
<td>“…the most common form of heat casualty and it is not associated with evidence of organ damage. It occurs when the body cannot sustain the level of cardiac output necessary to meet the combined demands of skin blood flow for thermoregulation and blood flow for the metabolic requirements of exercising skeletal muscle and vital organs”</td>
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<tr>
<td>Characteristics</td>
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<tr>
<td>Treatment</td>
<td>“The symptoms usually resolve within a few days, as the person becomes heat acclimatized. Treatment for this self-limiting condition is reassurance...”</td>
<td>“Victims...will recover rapidly once they sit or lay supine, though complete recovery of stable blood pressure and heart rate may take an hour or two... Rule out other causes of syncope, including more severe heat illness...Syncope occurring after more than 5 days of heat exposure may indicate dehydration or heat exhaustion. Syncope occurring during or after work in the heat may indicate heat exhaustion or exertional heat injury.”</td>
<td>“The immediate goal of treatment is relief of the cramps, not replacement of salt losses, which takes longer and is best accomplished by ingestion of salted foods or fluids over many hours.”</td>
<td>“Treatment should begin immediately to prevent progression to a severe heat injury.”</td>
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</table>

Symptoms: dizziness, headache, nausea, vomiting, tachycardia, muscle cramps, hyperventilation, generalized weakness, fatigue, ataxia, malaise, hypotension and transient alteration in mental status.
### Major heat injuries

<table>
<thead>
<tr>
<th>Exertional heat injury (EHI)</th>
<th>Heat stroke</th>
<th>Exertional rhabdomyolysis</th>
</tr>
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<tbody>
<tr>
<td>“…a continuum intermediate in severity between heat exhaustion and heat stroke. There is no consensus on diagnostic criteria for distinguishing EHI from heat exhaustion or heat stroke...”</td>
<td>“…characterized by elevated body temperature (&gt;40 °C or 104 °F) and central nervous system dysfunction that results in delirium, convulsions, or coma...a catastrophic medical emergency resulting from a failure of the thermoregulatory mechanisms... producing multi-organ dysfunction...”</td>
<td>“Exertional rhabdomyolysis is caused by skeletal muscle damage with release of cellular contents into the blood circulation...”</td>
</tr>
<tr>
<td>“…patients show evidence of organ (for example, liver or renal) or tissues (for example, muscle) injury or dysfunction but do not display sufficient neurological abnormalities to meet the usual criteria of heat stroke.”</td>
<td>“…often occurs under conditions the victim had been exposed to many times before, or while others are concurrently being exposed to the same condition without incident...”</td>
<td>“Manifestations can vary from asymptomatic elevations of skeletal muscle enzymes to muscle pain, weakness and tenderness with associated myoglobinuria with or without acute renal failure...”</td>
</tr>
<tr>
<td>“Suspected EHI patients should be immediately and actively cooled to a core temperature of 38.3°C... Fluid and electrolyte deficits should be corrected...return to regular duty should be guided by clinical and laboratory values”</td>
<td>“The most important therapeutic measure is rapid reduction of body core temperature...Active cooling should be started immediately and continued during evacuation...rectal temperature should be closely monitored....”</td>
<td>Admit to intensive care unit.</td>
</tr>
<tr>
<td></td>
<td>“Heat stroke should be the working diagnosis in anyone who has a heat casualty and has alteration in mental status...”</td>
<td></td>
</tr>
</tbody>
</table>
Hydration and health

It is easy to understand that proper hydration influences thermal regulation since approximately 60% of body mass is made up of water and sufficient liquid is needed for sweating (13), but it may be less obvious that proper hydration is necessary for essentially all physiologic systems of the body including the circulatory, muscular, cardiovascular, gastrointestinal and endocrine systems (14,15). Even in fit, acclimatized individuals, dehydration can limit the body’s effectiveness for dissipating heat (12). Relatively small decreases (<2%) of normal body weight due to dehydration can compromise physiologic function, cognitive function and productivity (13,14,16) and any time dehydration causes weight loss of greater than 3%, there is a risk of suffering exertional heat illness (14). Weight loss due to dehydration happens relatively easily, even in the most highly trained and fit athletes who can become dehydrated in an hour, especially if the athlete was dehydrated before starting strenuous exercise (14).

Heat and dehydration: Workers as a special population

The limited understanding we have regarding heat, hydration, cooling mechanisms, coping mechanisms and potential negative health outcomes comes mainly from research on two working populations that have similar metabolic loads but very different job descriptions from sugarcane harvesters: professional athletes and soldiers.

The idea that heat and dehydration negatively and disproportionately affects workers is not new. The US Military and the mining industry addressed the issue in the 1950’s (17-22). The World Health Organization (WHO) studied the issue in 1969 (23) and the International Standards Organization published recommended standards in 1989 (24,25). The EPA (26), the Centers for Disease Control and Prevention (CDC) (27), The National Institute for Occupational Safety and Health (NIOSH) (28) and OSHA (29) officially recognized the issue by the 1990s. In more recent years, agricultural workers (30) and athletes (5) have come into the spotlight regarding dangerous heat exposure, often as a response to tragedy rather than preventive research (27,31,32).

Heatwave research also provides some important clues. Mortality risk increases during heatwaves (11,33). For example, the European heatwave of 2003 has been blamed for some 70,000 deaths (34). In addition to heat stroke, there are a number of conditions, both fatal and non-fatal, linked to heatwaves including cardiovascular, pulmonary, renal and psychiatric illnesses (6,33).
Although most studies of the health effects of heat waves have focused on vulnerable populations such as the elderly, those living alone, or those with underlying health conditions (35–37), one study analyzed the heat effects on hospital emergencies in Murcia, Spain and identified that the average age of all heat stroke cases was 48.6 years and that 81% of them were men (38). Notably, 40% of heat stroke victims over a period of two years had suffered occupational exposure to heat and represented the highest risk group. The authors point out that relatively young working men are indeed a population for special attention when considering heat exposure. Similarly, during the 2-week heatwave in France in August 2003, more than 1,000 additional deaths occurred in the age range 45–64 years, with more men than women dying (39). These data point to the possibility of heat-related mortality among working people in France. Finally, workers can be especially affected by the less acute outcomes of heat stress, such as decreased concentration and response time, which may be responsible for accidents in some cases (9,13).

Climate change

Humans have known for most of their history that climate affects health. Doctors recommend that individuals suffering chronic conditions move to better weather, school teachers know that children are more likely to get sick during certain times of the year and hospitals can expect more patients during certain weather conditions.

Over a decade ago, the World Health Organization (WHO) made the link between climate change and human health, but overall, the public health sector was somewhat slow in responding to what is now a relatively well documented reality: climate change does and will continue to affect human health and the poor will be hit the hardest (40,41). Climate change has been aptly labeled as an “amplifier” of existing health risks (42). That is, public health professionals still need to act in the areas that have traditionally been important. Negative health effects resulting from climate change can come from heat stress; vector-borne and other communicable diseases; air pollution, food and water security; malnutrition and extreme weather (42–45).

The negative health consequences of climate change have the potential to accentuate already stark socio-economic differences that contribute to unjustifiable social determinants of health (43,46) as they disproportionately affect those with less resources for recovering from catastrophic events. In addition to the large-scale or extreme events that will increase with climate change, there will also be changes in the day-to-day risks faced by some people. One good example of this is heat exposure and outdoor workers (47).
Occupational health and climate change-related heat exposure

Just a few years ago, there was almost no documentation on worker-related climate change risks. In fact, the Working Group II Report of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report published in 2007 contained only one mention of workers. However, in less than a decade, clear risks and vulnerable populations have been identified (41,48–51) and frameworks (51,52) have been suggested for achieving protection for workers in the face of climate change. Outdoor workers are particularly vulnerable to heat, but risks among indoor workers have also been documented (6,53). Health-related risks are clear and, additionally, productivity of workers who must slow work to avoid over-heating will be a continuing area of importance (47). For example, one analysis in Nicaragua demonstrated projected climate would likely threaten not only workers’ health, but also the economic productivity of the country (54). The heat-related occupational outcomes will be linked to increasing temperatures, but also to an increase frequency, duration and severity of heatwaves (35).

Temperature is expected to rise in the tropics (41). Many workers in Central America are already exposed to considerable heat stress, especially during the hottest months of the year and estimates of the impact of heat stress on work capacity, calculated from the internationally recommended hourly rest periods during heavy physical labor, indicate that working people are already affected and future increased heat stress will create substantial additional losses in work capacity (53). Finally, increased ultraviolet radiation poses a current and increasing risk of skin cancer to nearly all outdoor workers (51).

The sugarcane industry

Sugarcane is grown in different countries with tropical climates and is an especially well-developed industry in Central America where some 520,000 hectares harvested represents a 1.3 billion dollar industry (55). Occupational hazards in the industry are vast and hazards for harvesters include insect and animal bites; inhalation of particulate matter; pesticide exposures; physical violence; inappropriate postures and physical loads; repetitive movements; poor work organization; machinery and tool-related hazards; heat and solar radiation (3,56–60). One of the contributing factors to a high accident rate is the intense nature of the harvest (“zafra” in Spanish) season which lasts approximately five to six months (November –April in Central America) during which production and work shifts are 24 hours a day, seven days a week. That is, once the production plant is started, it is not stopped until the harvest ends.
In Central America, several countries rely on migrant labor for the harvest season, a situation which increases occupational vulnerabilities and risks, especially since the workers are often subcontracted (56,61,62). Migrant workers generally live in labor camps with very basic facilities and sometimes unacceptable conditions. These conditions are coupled with the challenge of being far from family for the 5-6 month harvest season (56). Harvesters are usually paid according to how much they cut, a condition which invariably compromises the safety of workers, especially in relation to dehydration and heat stress (61,63,64).

Documented negative health and safety outcomes related to sugarcane harvesting include injuries due to accidents (3,58,60,65); injury due to violence (65); traffic accidents (66); musculoskeletal injuries (59,60,65); bagassosis (58,60,67); respiratory irritation (67–69) ocular irritation (56,60), skin irritation (56); oral cancer (70), chronic infections (58) and chronic kidney disease (71,72). Heat has been documented as a hazard (60,73), but documentation of heat-related outcomes was previously very limited. This work seeks in part to fill that gap and is part of increasing attention to issues of heat exposure in working populations including sugarcane harvesters (6,47,49,53,74,75).

The sugarcane industry in Costa Rica

With barely more than 51,000 square kilometers and under 5 million habitants, Costa Rica is a small country in the heart of Central America (Figure 1). Sugarcane is an important crop for internal consumption and export, where more than 12,000 individual farmers contribute to the cultivation of nearly 60,000 hectares that are processed in 12 industrial plants or sugarmills (“ingenios”) (76). This production makes up 14.4% of the agriculture and livestock gross domestic product (GDP) and 1.9% of the total GDP with an annual production value of close to 100 million USD (55). Sugar and related products represent 13.4% of traditional exports and 1.5% of all exports.
Figure 1. Costa Rica is situated in Central America. The shaded region is the province of Guanacaste.

Sugarcane production continues to increase in Costa Rica, partly due to its potential as a biofuel (56,77). Although produced throughout the country, over 50% of the harvest and processing takes place in the Guanacaste province located in the northwestern part of the country (Figure 1). Most of the province is low-elevation and the area registers the country’s hottest temperatures, making it ideal for sugarcane cultivation, but challenging for workers, particularly harvesters since the harvest season (zafra) takes place during the hottest part of the year (late November through mid-April) with average maximum temperatures of up to 36°C (78).

Much harvesting is done by workers cutting the cane manually with a machete. Although mechanical harvesting does exist and is used in all three companies in Guanacaste, the machine is very large (Figure 2a) and requires fields long enough to allow the machine to turn around. Likewise, fields must be flat and free of rocks, so much harvesting continues to be done by hand (Figure 2b). Although a number of Costa Ricans harvest sugarcane in Guanacaste, the majority is done by Nicaraguans. Many of them come year after year to one of the three companies in the province.
Chronic kidney disease of unknown origin in sugarcane workers

A devastating epidemic known as “chronic kidney disease of non-traditional origin” (CKDnT), “chronic kidney disease of unknown origin (CKDu)” or, in the case of Mesoamerica, “Mesoamerican nephropathy,” has been identified along the Pacific coast of Mesoamerica (71,72,79). Different from the typical chronic kidney disease that is linked to hypertension, diabetes and obesity that largely affects older adults (men and women) in many parts of the world, this disease (referred to as CKDnT here) is not linked to traditional risk factors. Although women are affected, the most clearly affected populations are men who do hard labor in hot conditions (71). In Mesoamerica, the most clearly affected populations are sugarcane harvesters including those in the Guanacaste province of Costa Rica where this study took place.

Similar epidemics of CKDnT have been reported in Sri Lanka, India and Egypt (72). It is still unclear whether the disease is the same in all countries, but similar epidemiological patterns and affected populations are seen in each case. The causes of CKDnT remain a mystery and thus fighting the disease is challenging. Current scientific consensus is that there are likely a combination of environmental and/or occupational factors involved that are influenced by social determinants of health and possibly by individual (biological) susceptibility (79,80). One of the most prominent hypotheses to date is that heat and/or chronic dehydration play a key role in the disease (79,81).
Objectives

• Document working conditions and heat in the Costa Rican sugarcane industry (Paper I)

• Quantify heat stress exposures faced by sugarcane harvesters in Costa Rica (Paper II).

• Evaluate the occurrence of heat stress symptoms and abnormal urinary parameters in sugarcane workers in Costa Rica (Papers III and IV).
Methods

This was a mixed methods (qualitative and quantitative) study designed to have three phases over the course of three harvest seasons: pilot, main study and intervention (Table 2). The pilot phase took place in a different company than the other phases of the study, but in very close physical proximity. The pilot phase focused on the industry as a whole in both the harvest and non-harvest season, while phases II and III were focused on workers employed to cut the cane with a machete. They are referred to here as “harvesters.”

The third phase of the study (intervention) was planned to implement and evaluate a hydration and rest intervention. However, the company where the research was carried out decided not to implement the recommendations we made, and instead distributed one hydration drink per day to all harvesters. As such, the planned evaluation (comparing outcomes of practice as usual and an intervention group) was not possible. We opted instead to evaluate liquid intake and urinary markers in a sub-set of sugarcane harvesters and qualitatively assess acceptability of the intervention. Table 2 provides an overview of the sequence and types of data collection used in the different phases and the resulting reports.
Table 2. Description of data collection stages and corresponding reports.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Harvest 1</th>
<th>Harvest 2</th>
<th>Harvest 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-harvest period preceding the harvest and 2009-10</td>
<td>2010-11</td>
<td>2011-12</td>
<td></td>
</tr>
<tr>
<td>Pilot evaluation and heat exposure</td>
<td>Main study</td>
<td>Main study</td>
<td></td>
</tr>
</tbody>
</table>

**Qualitative**

<table>
<thead>
<tr>
<th>Direct Observation</th>
<th>Paper I</th>
<th>Paper II</th>
<th>Paper IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviews</td>
<td>Paper I</td>
<td>Technical reports in Spanish (acceptability of company intervention)</td>
<td></td>
</tr>
<tr>
<td>Participatory workshop*</td>
<td>Paper I</td>
<td>Technical reports in Spanish (acceptability of company intervention)</td>
<td></td>
</tr>
</tbody>
</table>

**Quantitative***

<table>
<thead>
<tr>
<th>WBGT measurements</th>
<th>Paper II</th>
<th>Paper II</th>
<th>Paper IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Documentation of liquids consumed**</td>
<td>Paper IV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Symptom Questionnaire</td>
<td>Technical report in Spanish</td>
<td>Paper III</td>
<td>Paper IV</td>
</tr>
<tr>
<td>Metabolism/ WBGT Limit Value</td>
<td>Paper II</td>
<td>Paper II</td>
<td></td>
</tr>
<tr>
<td>Urinalyses</td>
<td></td>
<td>Paper IV</td>
<td></td>
</tr>
</tbody>
</table>

**Participatory workshop was not held in harvest 2 due to the PI being on maternity leave. Examples of materials from the final workshop in harvest 3 are included in the appendix.**

**Workers were asked to report how much water they consumed in harvest 2, but were unable to recall accurately.**

***Weight of harvesters was measured in harvest 2 and harvest 3, but did not give valid results due to scale failure in the heat.**

**Pilot evaluation on heat and the sugarcane industry and the need for future studies (Paper I)**

**Semi-structured interviews**

Paper I is based on exploratory semi-structured interviews held during the non-harvest period before harvest 1 with:

- 4 occupational health researchers with experience in the sugarcane industry
- 1 occupational health professional from a sugarcane company in Guanacaste
- 1 company nurse
- 1 company physician
- 17 workers (twelve from the plant and five field workers)
Participants were chosen because of their job titles or because they were recommended as a knowledgeable source by one of the interview participants. Participants from this phase of the study were from a different company than those in papers II-IV, but many of the workers have worked in multiple companies and previous research confirms that conditions are similar in the province’s three companies (3).

During harvest 1, a participatory workshop was organized with eight experienced harvesters. Discussion was held about perception of the research we were proposing as well as ideas to improve the study design. Qualitative data from this workshop were documented in technical reports written in Spanish and were used to guide planning and data collection for harvests 2 and 3. Interviews and the workshop contained questions about job tasks; heat conditions; perception of heat and heat-related outcomes; strategies or coping mechanisms for reducing heat-related health effects; possibilities for future studies; and whether or not it was important to conduct research about heat-related conditions.

**Description of work and heat exposure assessment (Papers I and II)**

Direct non-participatory observation was conducted for non-harvest field and plant workers before harvest 1 (Paper I) and for harvesters during six days of harvest 1 (Paper II). In both cases, researchers detailed specific job tasks as well the way workers dressed. Observation of sugarcane harvesters included the entire shift and also detailed the way harvesters carried liquids, consumed liquids, ate, interacted with coworkers and were transported to and from the field. Non-harvester observations took place during a short period (less than one hour per job title) and harvester observations included the entire shift. Observations were discussed by all researchers at the end of each day and were summarized to create a description of work and, in the case of sugarcane harvesters, used to calculate metabolic load according to the Technical Prevention Note (NTP) 323 (82) (based on ISO 8996) for the median age group observed using the components: baseline, postural, work and movement using the recommended estimates for men 30-34 years old.
METHODS

Wet bulb globe temperature

Wet Bulb Globe Temperature (WBGT) measurements were taken during the shift in all three harvests: 6 days during harvest 1; 7 days in harvest 2 and 3 days in harvest 3. A heat stress monitor model Quest Temp 36 with a precision of ±0.5°C was used to measure dry bulb temperature, globe temperature, and wet bulb temperature and calculate WBGT using the formula:

\[ 0.7 \text{ wet bulb temperature} + 0.2 \text{ globe temperature} + 0.1 \text{ dry bulb temperature} \]

Air velocity (m/s) and relative humidity (%) were also recorded. The monitor was placed in the field at waist height and turned on 15 minutes before the first measurement was taken. Measurements were automatically and manually (as backup) recorded at least every fifteen minutes.

Limit values

The NTP 322 (83) (based on the ISO standards 7730, 7933, 7243, 7716 and 8996) was used to evaluate the risk of heat stress and the corresponding WBGT limit values for hourly exposure. This limit is determined by plotting the metabolic load on the x-axis of a pre-determined curve for continuous work which gives the corresponding WBGT on the y-axis under which work can safely be carried out at 100% effort. The Occupational Safety and Health Administration (OSHA) Technical Manual (29) was then used to determine “permissible heat exposure threshold limit values” recommended work regimes per hour: 75% work-25% rest; 50-50% work-rest; or 25% work-50% rest.

Outcome data (Papers III and IV)

Study participants from harvest 2 (symptom reporting) were 106 harvesters and 63 male employees of the same company in different jobs (Table 3). Study participants from harvest 3 (urinalysis) were 48 harvesters from Nicaragua (Table 4).
Table 3. Demographics of harvesters and non-harvesters who participated in the symptom questionnaire (Paper III).

<table>
<thead>
<tr>
<th></th>
<th>Harvesters (n=106)</th>
<th>Non-harvesters (n=63)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, median (min, max)</td>
<td>34 (19, 60)</td>
<td>37 (20, 63)</td>
</tr>
<tr>
<td>Job category n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cane harvesters</td>
<td>106 (100)</td>
<td>NA</td>
</tr>
<tr>
<td>Office workers</td>
<td>NA</td>
<td>21 (33.3)</td>
</tr>
<tr>
<td>Field-based jobs (supervisors and one bus driver)*</td>
<td>NA</td>
<td>14 (22.2)</td>
</tr>
<tr>
<td>Plant/machine shop/storage worker</td>
<td>NA</td>
<td>18 (28.6)</td>
</tr>
<tr>
<td>Other (cafeteria,electrician, occupational safety staff, guard)</td>
<td>NA</td>
<td>10 (15.9)</td>
</tr>
<tr>
<td>Number of harvests worked, median (min, max)</td>
<td>5 (1,41)</td>
<td>4 (1,43)</td>
</tr>
<tr>
<td>Years in current post (counting current year), n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>First year</td>
<td>18 (17.0)</td>
<td>16 (25.4)</td>
</tr>
<tr>
<td>2 to 5 years</td>
<td>46 (43.4)</td>
<td>18 (28.6)</td>
</tr>
<tr>
<td>&gt;5 years</td>
<td>42 (39.6)</td>
<td>29 (46.0)</td>
</tr>
<tr>
<td>Years in school, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 years</td>
<td>14 (13.0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>1-6 years</td>
<td>78 (73.6)</td>
<td>7 (11.1)</td>
</tr>
<tr>
<td>7-12 years</td>
<td>13 (12.3)</td>
<td>26 (41.3)</td>
</tr>
<tr>
<td>&gt;12 years</td>
<td>1 (1)</td>
<td>30 (47.6)</td>
</tr>
<tr>
<td>Country of birth, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nicaragua</td>
<td>89 (84.0)</td>
<td>2 (3.2)</td>
</tr>
<tr>
<td>Costa Rica</td>
<td>17 (16.0)</td>
<td>61 (96.8)</td>
</tr>
<tr>
<td>Housing during the harvest, n (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A labor camp</td>
<td>87 (82.1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>In nearby house or apartment</td>
<td>19 (17.9)</td>
<td>63 (100)</td>
</tr>
<tr>
<td>Drink alcohol, n (%)</td>
<td>48 (45.2)</td>
<td>48 (76.1)</td>
</tr>
<tr>
<td>Smoke, n (%)</td>
<td>26 (24.5)</td>
<td>11 (17.5)</td>
</tr>
</tbody>
</table>

*The bus driver was included in this category since his ambient heat exposure and required physical effort was similar to the supervisors.
Table 4. Characteristics of harvesters participating in urinalysis from harvest 3 (Paper IV).

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Harvesters (n= 48)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height, median (min, max)</td>
<td>1.7 (1.6-1.9)</td>
</tr>
<tr>
<td>Weight, median (min, max)</td>
<td>63.5 (52.0-89.0)</td>
</tr>
<tr>
<td>Body Mass Index, median (min, max)</td>
<td>22.9 (17.8-30.3)</td>
</tr>
<tr>
<td>Age, median (min, max)</td>
<td>34 (20-54)</td>
</tr>
<tr>
<td>Number of harvests worked, median (min, max)</td>
<td>4 (1-18)</td>
</tr>
<tr>
<td>Number of harvests worked at this company, median (min, max)</td>
<td>4 (1-13)</td>
</tr>
<tr>
<td>Drink alcohol, n (%)</td>
<td>20 (46.5)</td>
</tr>
<tr>
<td>Smoke, n (%)</td>
<td>13 (30.2)</td>
</tr>
<tr>
<td>Previously diagnosed medical conditions n (%)</td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>2 (4.7)</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>1 (2.3)</td>
</tr>
<tr>
<td>Urinary tract infection</td>
<td>15 (34.9)</td>
</tr>
<tr>
<td>Within the last 2 months</td>
<td>5 (11.6)</td>
</tr>
<tr>
<td>3-12 months ago</td>
<td>10 (23.3)</td>
</tr>
<tr>
<td>Kidney problems (infection, stones or unspecified)</td>
<td>3 (7.0)</td>
</tr>
</tbody>
</table>

*Five workers did not complete the demographic questionnaire.

**Symptoms**

In the second year of the study, we invited harvesters and non-harvesters from the same company to participate in an orally-administered symptom questionnaire. Workers were categorized into high heat exposed (harvesters), intermediate heat exposure (part of the processing plant, machinery shop, storage area or cafeteria) and non-heat exposed (office workers in air conditioning).

Symptoms were categorized into: *heat and dehydration-related symptoms* (headache, tachycardia, muscle cramps in the arms or legs, fever, nausea, difficulty breathing, swelling of hands or feet, dizziness, vomiting, fainting, dry mouth and dysuria), using criteria from the US Military and previous research with sugarcane workers (7,84) and *non-heat related symptoms known to be related to the sugarcane cutting* (pain in upper part of back and pain in lower part of back) (3,67) and *not-known to be related to harvesting* (stomachache, diarrhea, difficulty buttoning shirt, nosebleed and earache). For each symptom, the participant was asked whether he had experienced it at some point during the current harvest. If the answer was positive, he was asked whether he experienced the
symptom “almost every day,” “at least once a week,” “at least once a month,” “2-3 times during the current harvest,” or “only once.”

Chi-square tests and gamma statistic were used to evaluate the possibility of differences and significant trends in symptom reporting across increasing job-categories of heat exposure. We hypothesized a priori, that heat and dehydration-related symptoms would occur more frequently among harvesters than among non-harvesters, as would other symptoms known to be related to cane cutting; and that there would be no relevant differences between the groups with regard to symptoms not known to be related to cane cutting.

**Urine samples**

In harvest 3, urinalysis was conducted pre- and post-shift in 48 sugarcane harvesters on three days. Researchers arrived at the labor camp at approximately 3:45 am, collected a morning urine sample, visually confirmed the amount and type of liquids carried to the field and then accompanied the men to the field. As each harvester finished working, researchers collected a second urine sample and verified the types and amounts of liquids consumed by checking the amounts left in containers.

Urinary parameters were dichotomized: pH ≤ 5 and urine specific gravity (USG) ≥ 1.025 considered as indicators of dehydration, and presence of protein (≥ 30 mg/dL); blood traces or more; leucocytes in sediment ≥ 5; erythrocytes in sediment ≥ 3; and casts. Changes over the workday in the urinary parameters were evaluated with the McNemar test for paired proportions. Results from the workers with incomplete urine samples, who were not included in these analyses were compared to those with complete data, to qualitatively assess a potential selection bias.

**Ethical considerations**

Sugarcane harvesters are a vulnerable population given their precarious labor situation often magnified by poverty and migrant status. Although company management gave permission for workers to participate in the study and knew which harvesters were participating, management did not have access to which harvesters reported symptoms or had specific outcomes. Data collection (particularly symptom questionnaires) had to be done in the field, but researchers assured they were done with no supervisors in the vicinity. Some harvesters were reserved about speaking in a one-on-one situation with researchers; however, most workers have a cutting partner that they work with every day who is gener-
ally a person of complete confidence. Some workers felt more comfortable completing symptom questionnaires in the presence of their cutting partner.

Workers provided written consent for all portions of the study, but since literacy was limited, consent forms were read to all workers before signing. Participation was completely voluntary. Participants were permitted to withdraw from the study or decline to participate in any part of the study at any time and for any reason. All necessary approvals for protocol and consent forms were given by the Ethical Committee (CEC) at the Universidad Nacional in Costa Rica. Results from each year were presented to participating workers (some from the previous year and some new) both orally and in simple written documents (see appendix). Laboratory results of urinalysis were given orally and in paper form. However, a few workers did not want to know their results. This decision was respected by researchers.
Results

Working conditions and heat in the sugarcane industry (Papers I and II)

Pilot study: Work in the harvest and non-harvest season

Although the main focus of this work was on sugarcane harvesters, the sugarcane industry includes a number of different job tasks. The pilot phase of the study identified two main areas where workers are exposed to heat: field work and processing plant (sugar mill). Both areas include workers during the harvest and non-harvest (maintenance) seasons. Field tasks during the harvest season are mainly cutting and planting cane. Field tasks during the non-harvest season focus on irrigation, field upkeep and application of agrochemicals. Mill work during the harvest season includes all tasks beginning with unloading the harvested sugarcane from trucks and ending with the production of refined sugar products. During the non-harvest season, workers are tasked with general upkeep of machinery and infrastructure.

Non-harvest period field work

Field work during the non-harvest period includes irrigators, maintenance workers and applicators. Irrigators work alone in large fields with oversight by a supervisor who drives from field-to-field. They continually walk and carry a shovel with an extra-long handle used to clear water canals and as a walking stick to cross the large irrigation ditches. Maintenance workers have tasks such as picking up rocks in the field, cutting weeds and grass with a machete, picking up sugarcane left behind in the field, fixing leaks in the irrigation system and keeping irrigation canals free of debris. Applicators are workers assigned to apply agrochemicals. Some workers are inside an enclosed air-conditioned tractor cab, while others use a backpack sprayer or a mechanical “boom” sprayer pulled behind a four-wheeled motorcycle. With the exception of tractor drivers, field workers spend most of the shift on their feet and walk a considerable amount. They are exposed to direct sunlight for the entire shift, but on some days, they may be near trees or other sources of shade under which they can seek brief respite and leave their lunches and water jugs to keep them from overheating. Some workers reported taking breaks when their task load allowed. Generally, the non-harvest season tends to be somewhat cooler (Mean maximum temperature 31.3-34.2°C) and is a more relaxed working environment than the harvest season. Workers in the non-harvest season are generally full-time, year-round employees of the company.
RESULTS

Mill work
Non-harvest season workers are also employed in the machine shop and plant, but were not included in the pilot due to low heat exposure. During the harvest season the plant operates 24-hours a day seven days a week. The mill is run by electricity produced onsite by burning waste products of the sugarcane. This and virtually every other process in the plant creates heat leading to extremely hot working conditions complicated by periodic purges of steam. The mill is entirely covered by a roof, but heat and humidity were high enough to cause metal stairs and handrails to be uncomfortably hot to the touch.

Harvest season workers include those in the following areas: patio; tachos; centrifuges, clarifiers and evaporators; and calderas (ovens). *Patio workers* are in an outdoor area where the sugarcane is unloaded from truck. *Tacheros* control the quality of sugar in the “tachos” area of the plant by controlling pressure and volume of large tanks. Their job is quite detail-oriented and requires experienced workers. Workers in the areas of *centrifuges, clarifiers and evaporators* must also pay attention to detail. The centrifuge area is particularly hot because the large tanks release heat and steam. All workers are on their feet for most of the shift, but only some patio workers have tasks requiring notable physical effort. Most workers are able to sit during parts of their shift.

Calderas are ovens that burn bagasse to produce the electricity that runs the plant. A team of 4-5 *caldera workers* cleaned the ovens with metal poles and shovels literally pulling the smoldering ash out and placing it on a palette of a forklift. This process took approximately 2.5 hours and was done twice per 12-hour shift. These workers are exposed to very intense metabolic load and heat (ovens are over 250°C), risk of burns, and inhalation of particulate matter. When not cleaning the oven, they help with other tasks in the plant.

Heat and water-related concerns
The health workers interviewed voiced concerns that severe dehydration cases they had seen in workers are linked to complex social issues. For example, workers may not seek medical care because they lack documentation or because they fear losing their job and therefore may work in the fields while sick. Health workers also expressed concern that hydration with water may not be sufficient and expressed desire for information on electrolytes or nutritional inputs to complement hydration.

Field workers expressed concern about kidney disease. For example, one worker reported, “many co-workers are affected by kidney problems” and others expressed that drinking water is important “for your kidneys.” On the other hand,
they expressed that one must be careful not to consume too much water before doing machete work, as to avoid “jumbling up and bothering the stomach.” Both field and plant workers complain of hot water, but at the same time, avoid very cold drinks because of a belief that drinking cold liquid while hot is bad for the body. Some workers complained about the taste, and some noted that the mineral content was high, commenting for example, that showerheads get blocked with mineral deposits. Both field and plant workers expressed concern that water might be contaminated. This was of particular concern related to kidney disease. This led some workers to drink less. One plant worker reported that he and co-workers add bleach to water to purify it.

Strategies for coping with heat

When asked whether they believe the heat or “especially hot days” affect their productivity, most field workers said that they feel they get tired faster, but most of them also qualified their statement saying that they manage to complete their tasks. Those whose work required attention to detail reported taking caffeinated aspirin pills when feeling tired and others reported taking acetaminophen for headaches. Company-level strategies for improving hydration were limited to the plant where water stations were available and plastic bags of a hydration (sports) drink were sometimes given out. Oven cleaners were also allowed a free drink from the cafeteria during the shift. Only tacheros had access to air conditioned chambers where a computer was stored, but were often reluctant to use it due to a belief that moving between hot and cold temperatures is bad for the body. Most plant workers wore long sleeves, long pants, a hard hat and gloves, but it was common to see workers take off gloves due to the heat. Some plant workers reported individual coping strategies. Caldera workers, for example, put their feet (in rubber boots) in cold water to cool off or dumped water on their heads after cleaning the ovens. All workers reported preferring the night shift over the day shift because it was cooler.

Field workers however did not have any company-provided hydration. Field workers wrap plastic water jugs in wet cloth to slow the inevitable heating of water in the sun. In order to protect themselves from solar radiation, field workers wore long sleeves, long pants and a neck covering (usually a handkerchief) and rubber boots or “work” boots. Many workers wore two shirts to lessen the burning sensation of the sun.

Description of work: Harvesters

Sugarcane harvesters wear the same clothes described for other field workers above. Additionally, some workers wear a bandana over their mouth and nose to
RESULTS

minimize inhalation of soot and some wear a shin guard on the leg opposite their cutting arm. They carry a machete and a tie a slender file around the waist for sharpening the machete. Workers swing the machete back at about shoulder level while bending at the knees and/or waist to cut the stalk a few centimeters above ground level (Figure 2b). After cutting multiple stalks, they gathered the cane in their arms and place in a row to be picked up later by tractors with crane attachments (Figure 3). Finally, they gather the leftover leaf material and place it in a row apart from the cane.

Workers were organized into sub-contracted groups composed of 60-150 workers. Those that lived in a labor camp generally left the camp at 4:30-5:00am and started cutting between 5:00-6:30am. In the first year of the study, workers were often transported standing in the back of a cattle truck. This practice, which meant that the afternoon commute led to further heat exposure as workers had to stand, shoulder-to-shoulder surrounded by the already-hot bodies of their co-workers, either without a tarp on top (leading to more solar radiation exposure) or with a tarp (decreasing wind and making evaporative cooling less efficient) was changed in the second year at the recommendation of researchers, but is still relatively widespread in the region.

Eating habits varied. Some workers ate breakfast before leaving the camp, while others took their breakfast to the field. Cane is typically harvested in pairs of workers and is planted in long rows (Figure 3). No mandatory breaks were held and there was generally no shade available during the work shift. Workers were allowed to stop or rest whenever they wished, but they were paid by how much they cut.

Figure 3. Workers starting to cut a field (left) and later in shift (right). Sugarcane harvesting requires lifting a machete and swinging with force to cut the cane a few inches from the ground. Workers bend and/or waist to achieve this. (Photos: Jennifer Crowe)
The company provided no liquid and workers had to carry all liquid they wished to consume between leaving the labor camp and arriving home (7–9 hours). Workers generally carried two 4-L jugs of water which they wrapped in wet cloth as described above. Workers left their jugs at the beginning of the row until and, when thirsty, walked back 10–50 m to where their water was last left. After stopping to drink, workers then carried the jug to the next starting point for cutting.

Shade is almost never available as the cane needs full sun for proper growth. Despite continuous efforts and legislation to the contrary (85,86), cane is usually burned the night before the harvest. This has been justified by the industry in to make harvesting and processing more efficient (87). One result of this is that workers finish their shifts the field literally covered in ash.

**Heat exposure: Sugarcane harvesters (Paper II)**

**Climate variables**

WBGT were measured in all three harvests with similar results. Here, results from Paper II (Harvests 1 and 2) are summarized. WBGT tended to increase sharply around 7:00 am on most mornings and continued to rise until measurements were stopped at 12:00 pm. The coolest WBGT measurement was 19.7°C at 6:45 am and the highest was 33.9 at or after 10:15 am. Winds ranged from 0.1 to 7.1 m/s but the average wind per day ranged from 0.5 to 1.8 m/s.

The metabolic load of cutting sugarcane was estimated to be approximately 261 W/m² (6.8 kcal/min) (Table 5) corresponding to a limit of 26°C WBGT for avoiding heat stress. WBGT measured during the work shift increased sharply starting around 7:00 am on most mornings and continued to rise throughout the morning. There was a risk of heat stress for harvesters as early as 7:15 am on some mornings and by 9:00 am on all mornings. Between 8:15 and 9:00 am, more than half of the WBGT measurements taken would require only working 50% of each hour according to OSHA recommendations, and starting at 9:15 am, only 25% work per hour is recommended (Figure 4).
Figure 4. WBGT during the work shift compared to limit values for preventing heat stress (Paper II).

Table 5. Calculation of metabolic load for sugarcane harvesters (males age 30-34) using NTP guidelines (Paper II).

<table>
<thead>
<tr>
<th>Component</th>
<th>Definition</th>
<th>W/m² (Kcal/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline metabolism</td>
<td>The energy consumption of a person lying down and at rest</td>
<td>46 (1.2)</td>
</tr>
<tr>
<td></td>
<td>needed to maintain vegetative functions (such as breathing and circulation) (males age 30-34)</td>
<td></td>
</tr>
<tr>
<td>Postural component</td>
<td>The additional energy consumption that a person needs to maintain a particular posture (on foot, inclined)</td>
<td>30 (0.8)</td>
</tr>
<tr>
<td>Work component</td>
<td>The additional energy consumption as a result of type of work according to body part in motion and intensity (one arm, intense)</td>
<td>75 (1.9)</td>
</tr>
<tr>
<td>Movement component</td>
<td>The additional energy consumption that is required for movement from one location to another at a specified velocity (moving at 2-5 km/hr with no incline and carrying no weight)**</td>
<td>110 (2.8)</td>
</tr>
<tr>
<td>Total metabolic load</td>
<td></td>
<td>261 (6.8)*</td>
</tr>
</tbody>
</table>

* Assumes a body surface area of 1.8 m²

** Workers carry a machete and a file for sharpening at all times as well as two 4-liter water jug when arriving to and leaving from a worksite and each time when they need a drink. Nonetheless, since the guidelines only provide one estimate for the metabolic load of “carrying 1-10 kg” while working, the weight carried has been ignored to avoid over-estimation of metabolic load. It is possible, however that this decision results in a slight under representation of the metabolic load.
Health outcomes (Papers III and IV)

*Symptoms*
Half of the sugarcane harvesters (n=54, 51%) experienced headaches at least once per week and of these, 20% had a headache almost every day during the harvest season. This was significantly different from non-harvesters (n=16, 25% once a week; n=3, 2% every day; p=0.001). Over a quarter of harvesters had other heat-related symptoms once a week: tachycardia (35%), dysuria (28%) and muscle cramps in arms and legs (25%), which was significantly different from non-harvesters. The following symptoms were also experienced more often by harvesters at least once per week: fever, nausea, difficulty breathing, dizziness and vomiting (p<0.05) (Table 6).
Table 6. Frequency of symptom reporting by sugarcane harvesters and sugarcane non-harvesters (Paper III).

<table>
<thead>
<tr>
<th>Heat exhaustion symptoms</th>
<th>At least once per week</th>
<th>Harvesters (n=106)</th>
<th>Non-harvesters (n=63)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n</td>
<td>%</td>
<td>n</td>
</tr>
<tr>
<td>Headache</td>
<td>54 50.9</td>
<td>16</td>
<td>25.4</td>
<td>0.001</td>
</tr>
<tr>
<td>Tachycardia</td>
<td>37 34.9</td>
<td>3</td>
<td>4.8</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Muscle cramps arms/legs</td>
<td>26 24.5</td>
<td>7</td>
<td>11.1</td>
<td>0.037</td>
</tr>
<tr>
<td>Fever</td>
<td>19 17.9</td>
<td>2</td>
<td>3.2</td>
<td>0.005</td>
</tr>
<tr>
<td>Nausea</td>
<td>18 17.0</td>
<td>0</td>
<td>0.0</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Difficulty breathing</td>
<td>14 13.2</td>
<td>0</td>
<td>0.0</td>
<td>0.003</td>
</tr>
<tr>
<td>Dizziness</td>
<td>12 11.3</td>
<td>1</td>
<td>1.6</td>
<td>0.033</td>
</tr>
<tr>
<td>Swelling hands / feet</td>
<td>8  7.5</td>
<td>0</td>
<td>0.0</td>
<td>0.026</td>
</tr>
<tr>
<td>Vomiting</td>
<td>4  3.8</td>
<td>0</td>
<td>0.0</td>
<td>0.298</td>
</tr>
<tr>
<td>Fainting</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dehydration symptoms</th>
<th></th>
<th>Harvesters (n=106)</th>
<th>Non-harvesters (n=63)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry mouth</td>
<td>34 32.1</td>
<td>14 22.2</td>
<td>0.189</td>
<td></td>
</tr>
<tr>
<td>Dysuria</td>
<td>30 28.3</td>
<td>2  3.2</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Non-heat related symptoms</th>
<th></th>
<th>Harvesters (n=106)</th>
<th>Non-harvesters (n=63)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Related to cane cutting</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pain in lower part of back</td>
<td>67 63.2</td>
<td>23 36.5</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Pain in upper part of back</td>
<td>59 55.7</td>
<td>21 33.3</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Sneezing</td>
<td>58 54.7</td>
<td>15 23.8</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>Rhinorrhea</td>
<td>27 25.5</td>
<td>3  4.8</td>
<td>0.001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Not related to cane cutting</th>
<th></th>
<th>Harvesters (n=106)</th>
<th>Non-harvesters (n=63)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stomachache</td>
<td>12 11.3</td>
<td>5  7.9</td>
<td>0.499</td>
<td></td>
</tr>
<tr>
<td>Diarrhea</td>
<td>3  2.8</td>
<td>0  0.0</td>
<td>0.294</td>
<td></td>
</tr>
<tr>
<td>Difficulty buttoning shirt</td>
<td>3  2.8</td>
<td>0  0.0</td>
<td>0.294</td>
<td></td>
</tr>
<tr>
<td>Nosebleed</td>
<td>2  1.9</td>
<td>0  0.0</td>
<td>0.530</td>
<td></td>
</tr>
<tr>
<td>Earache</td>
<td>1  0.9</td>
<td>0  0.0</td>
<td>1.000</td>
<td></td>
</tr>
</tbody>
</table>

In addition to reporting heat-related symptoms *more often* (more times per week), harvesters also reported *more* heat-related symptoms than the non-harvesters: 82% of harvesters reported one or more heat-related symptoms at least once a week compared to 49% of non-harvesters; for ≥ 2 symptoms, these figures were 59% vs 19% and for ≥3 symptoms 42% vs 3%. A clear trend is seen for the majority of heat and dehydration-related symptom across job-exposure categories (Figure 5) with the percentage of workers reporting heat and dehydration-symptoms once a week increasing as heat exposure increases.
Urinary Parameters

Liquid consumption, WBGT and hours worked on days in which urinalysis were performed are summarized in Table 7.

Table 7. Liquid consumption, working times and WBGT during harvest 3 (Paper IV).

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Started cutting cane</td>
<td>5.30 am</td>
<td>5.15 am</td>
<td>5.30 am</td>
</tr>
<tr>
<td>Hours worked cutting, median (min, max)</td>
<td>6.5 (5.5-7.25)</td>
<td>5.8 (5.75-7.75)</td>
<td>5.0 (3.5-6.0)</td>
</tr>
<tr>
<td>WBGT during shift (°C), median (min, max)</td>
<td>27.5 (22.1-31.4)</td>
<td>29.6 (18.1-31.8)</td>
<td>27.4 (19.7-29.6)</td>
</tr>
<tr>
<td>Time of first measurement above limit value 26°C</td>
<td>8:30am</td>
<td>8:00am</td>
<td>7:15am</td>
</tr>
<tr>
<td>Water consumed (L), median (min, max)</td>
<td>5.0 (3.0-8.0)</td>
<td>4.0 (0.25-8.0)</td>
<td>3.25 (1.25-7.25)</td>
</tr>
<tr>
<td>Total liquid (water plus other) consumed (L), median (min, max)</td>
<td>5.75 (3.25-9.25)</td>
<td>5.0 (1.0-9.0)</td>
<td>4.25 (1.25-8.50)</td>
</tr>
</tbody>
</table>
Indicators of dehydration became more frequent over the work shift whereas other abnormal outcomes (blood, proteinuria, leucocytes and casts) were more common in the post-shift samples. These differences were statistically significant for proportions of workers with at least one of three abnormal outcomes (McNemar’s p<0.05) (Figure 6).

Although they were more common in the post-shift samples, dehydration indicators also common in pre-shift sample and most (60%, n=29) workers had at least one high USG sample (n=29). For example, 83% of workers post-shift and 29% pre-shift had pH≤5 at least once and 52% of workers post-shift and 27% pre-shift had a high USG at least once. Many workers demonstrated an increase in USG from pre to post-shift (up to ≥1.025): 44, 63 and 54% on days 1-3. In addition, between 6-10% each day had USG≥1.025 in both samples. A total of 60% of all workers had at least one sample with USG≥1.025.

Proteinuria was most common in pre-shift samples, increased over the week and was most common in pre-shift samples: 15, 52 and 65% respectively. Leucocytes (>5) were slightly more common in the pre-shift samples: 56, 40 and 58% of workers on days 1-3. Erythrocytes (≥3) were also slightly more common in pre-shift samples: 35, 19 and 25% on days 1-3. Casts were also common and present in morning samples as follows: hyaline: 19%, granular 60%, leucocytes 33% and erythrocyte 8%.

**Figure 6.** Percentages of workers with at least one abnormal test result in three pre-shift (light grey) versus three post-shift (dark grey) samples. Asterisk (*) signifies p<0.05 using McNemar test on paired proportions.
**Discussion**

This study demonstrates that heat exposure is an important occupational health risk in the sugarcane industry. Heat exposed workers were identified in both seasons, the field and the mill. The most notable examples of heat-exposed workers were caldera workers and sugarcane harvesters. This study focused on sugarcane harvesters since they face additional challenges known to increase risks for workers: they are subcontracted, temporary and, often, migrant workers.

This discussion focuses on the most important results of this project. First, we discuss the choice of WBGT as way of estimating heat stress. Second, we raise the possibility that sugarcane harvesters might be able to override natural mechanisms to prevent overheating during heat exposure. Third, we describe the implications of the symptom and urinary outcomes documented in this study. Fourth, we suggest a path forward by giving concrete answers to common questions about protecting heat-exposed sugarcane harvesters. Finally, we suggest policy actions and future research which could also improve current work conditions for this population.

**Setting limits: the pros and cons of WBGT**

The WBGT measurements compared to the hourly limit value for the calculated metabolic load demonstrate that sugarcane harvesters do strenuous work in harsh climatic conditions and, according to international standards, are at risk of heat stress for the majority of the work shift. The biggest limitation of the heat exposure portion of this study is one that plagues most assessments of workplace heat exposure: guidelines used were qualitative and designed to prevent heat stress rather than measure it. We opted to use WBGT limit values which have been criticized as overprotective, untested in non-Caucasian populations, and difficult to calculate (88). There are multiple indices, models and thresholds available for estimating the probability of heat stress including, but not limited to, the Sweat Rate Index; the U.S. Navy Physiological Heat Exposure Limit (PHEL) curves; Thermal Work Limit (TWL); the American Conference of Governmental Industrial Hygienists’ (ACGIH) Heat Stress and Strain Threshold Limit Values; NIOSH’s Recommended Alert Limit (RAC) and Recommended Exposure Limit (REL); and the Predicted Heat Strain model (24, 89-92, 94).

However, there is general consensus that WBGT is a reasonable way to evaluate risk in field conditions (5,7,14,92) and academic debate on the precision of these indices, while helpful for advancing science, runs the risk of overshadowing the fact that workers such as those described in this work are at risk for negative heat-related health conditions. Importantly, OSHA guidelines referenced here assume that workers are acclimatized and have “adequate water and salt intake”
(29). As shown in the third phase of this study (Paper II), workers do not have access to company-provided liquid and many workers do not drink adequate water during the shift.

It is possible that harvesters tend to be physically fit and acclimatized to hot weather and therefore may be less vulnerable than the average worker threshold limits try to protect. On the other hand, the low socio-economic status and migrant status of the majority of workers as well as the advanced age of many workers means that underlying health and nutrition complications make the most conservative guidelines appropriate for this population.

**Natural physiological defenses against overheating: Can they be overridden by sugarcane harvesters?**

It has been postulated that the physiological limits of the body are sufficient for protecting workers against increases in core temperatures and it is common to hear this as justification for current work practices such as letting the workers decide whether and when to take rest breaks. It may be true that cane harvesters self-pace to some degree by slowing or stopping to sharpen machetes or walking back to get their water. However, when choices about resting, drinking water or eating are left up to the individual worker, they cannot be relied upon as protection measures, especially when workers are not paid for their rest time, or in the presence of productivity measures such as being paid according to the amount of cane cut (93,94). While it is possible that some workers in this study made the decision to leave the field early and forego further income in response to their body’s inability to continue, it is likely that others were able to push past the signals (such as thirst, fatigue and headache) to slow down.

The body’s ability to override its own protective systems is not well studied, but it seems possible that poverty is a strong enough motivator to achieve this. A similar phenomenon has been noted in other high-intensity professions such as soldiers and professional athletes who, as one researcher puts it (15), are “populations committed to maximal physical exertion.” As Binkley and colleagues describe this phenomenon, those who are committed to what they are doing “override the normal behavioral adaptations to heat and decrease the likelihood of subtle cues being recognized” (5). In the case of athletes, this drive makes an individual competitive enough to win. In the case of workers who are paid according to their productivity, the motivational force may be survival in the face of poverty.
DISCUSSION

Symptom outcomes
The biggest limitation of the symptom data was the notable socio-demographic differences between the comparison groups of harvesters and non-harvesters. These comparison groups allowed for more valid comparisons since environmental exposures were similar between the two groups, but led to notable differences in housing and education. Given the role that social determinants of health play in predicting negative health outcomes (46), it is possible that the poorer social conditions of harvesters played a role in increased symptom reporting. However, low reporting of symptoms not related to heat or cane harvesting (i.e. diarrhea) indicates that harvesters were not systematically reporting more symptoms of any type than non-harvesters.

In addition, migrant status, a strong determinant of health, did not seem to play a role in symptom reporting. We tested this by comparing the Nicaraguan harvesters living in labor camps with the Costa Rican harvesters from the area, expecting to see higher symptom reporting in the Nicaraguan workers. However, the opposite was true: Costa Ricans reported slightly more symptoms. This is another indication that social-economic conditions were not an important determinant in the reporting of the symptoms by this study population.

Other limitations include the similarity of heat-related symptoms to other common health conditions such as the flu, the fact that recruitment of heat-exposed and non-heat exposed workers included only workers present when research took place (potentially excluding workers who were absent due to heat exhaustion), the reliance on self-reported rather than diagnosed conditions and the use of a questionnaire which had been pilot tested but not validated.

Despite weaknesses, the results of this study make it clear that many harvesters suffer notable undesirable symptoms, many of which appear to be directly related to heat exposure: 20% of harvesters have a headache every day and a quarter of the harvesters have symptoms such as tachycardia and muscle cramps at least once a week. Most (82%) of the workforce had at least one heat-related symptom at least once a week, and 59% had at least two heat-related symptoms at least once a week. Less frequent but more debilitating symptoms such as fainting (syncope), vomiting and dizziness were also reported. Such a labor force cannot work to its potential and clearly needs to be protected from negative health outcomes.

Choosing dehydration hydration markers
Determining states of hydration and dehydration has long been debated and no agreement exists on the ideal marker for dehydration in field studies. In fact, it has been claimed that “research on the potential health impact of dehydration
has not progressed because there is no single valid measure of hydration status” (95).

The most trusted indicators (for example, pre and post-shift weight) are often impractical in workplace field studies. For example, in this study, attempts were made to obtain weight in the field, but the scales failed in the heat. Better scales could have avoided this problem, but even if scales had worked, soot and sweat-laden clothes post-shift made weighing in the field invalid. Likewise, weighing in the nude was culturally inappropriate for this study and would have been logistically very challenging had workers been willing to take off their clothes in the field.

USG is not an ideal indicator of hydration since it can provide false positives (a non-hydrated person appearing hydrated) in cases where a person consumes large amounts of water in a short time (13) and somewhat subjective when measured by dipstick. However, it is one of the most practical methods available for field studies and general agreement exists that USG remains a reasonable and useful indicator of hydration status (14, 96).

**Dehydration in harvesters**

In this study, most workers experienced increased urine concentration and acidification over each work day and over half (n=25, 52%) of the workers had at least one afternoon USG indicative of dehydration. Also of note is that at least 27% (n=13) had a morning sample with USG ≥1.025. Starting the shift hydrated is well-documented as an important component of worker hydration (93,97).

The hottest (highest WBGT) conditions and the longest hours worked were on day 2. On this day, 68% had increasing USG from pre to post-shift and almost half of these to very concentrated urine. A similar phenomenon was seen on day 3 (n=30, 63%) although the day was cooler and the work time shorter. It is challenging to interpret USGs on a daily basis as a function of metabolic load as the physical effort required for cutting cane depends on the weather conditions as well as on how entangled the cane has grown. In addition, it is very likely that USGs are influenced as much by exertion and hydration on previous days as they were by same-day conditions (5). The high USGs of day 3 are an example of this, where the men who stayed in the field the longest on day 2 cut less than usual on day 3 and all men worked less on day 3 than days 1 and 2. Likewise, pre-shift protein in urine increased over the three days and was the highest on day 3.
Abnormal urine outcomes in harvesters

In addition to USG and pH indicators consistent with dehydration, a striking number of workers had urine samples with abnormal presence of blood, protein, leucocytes, and casts, particularly in pre-shift samples. Although sediment alterations have been reported as a result of heavy exercise such as sporting events (98), the range of some of these abnormalities (proteinuria, leukocyturia and microhematuria) documented in this study is consistent with renal injury.

Also of concern were samples from men who had incomplete urine samples and were therefore not included in the statistical analyses. The reasons were absence from work (likely related to being ill in most cases) and, in several cases, not being able to urinate (a sign of dehydration). Leaving these participants out of the analyses likely led to an under-representation of the alterations at the group level.

Potential outcomes: The case of CKDnT

The acute risks of heat exposure are relatively well documented (2), but little is known about the long-term health effects of chronic exposure to heat stress conditions and/or chronic dehydration. It is important to consider the possibility of yet-undocumented effects of long-term heat exposure.

Of particular note for this population is increasing evidence suggesting that chronic heat exposure and/or dehydration may play a key role in causing or accelerating chronic kidney disease (79,81). A large cohort in Thailand found an association between occupational heat stress and incident self-reported medically-diagnosed kidney disease (99) and recent experimental evidence shows that recurrent dehydration can induce renal injury in mice via a fructokinase enzyme dependent mechanism (100). Likewise, heatwaves are associated with increased rates of negative renal outcomes (101–104), providing additional clues to the potential links between exposure to environmental heat stressors and renal outcomes.

It is also feasible that heat exposure changes metabolism in a way that might increase the risk of a still-unidentified toxin affecting the kidney. For example, animal studies have shown that high temperature, humidity and physical activity can have a direct impact on toxicology, either by increasing the rate at which toxins enter the body or by altering the physiological response within the body (105). So far, little evidence has been found of a specific toxin (71), but the fact that women in Guanacaste have double the mortality rate of CKD compared to the rest of the country (106), gives reason to investigate the possibility. Of note
is that, even in the absence of an environmental toxin in the causal pathway of CKDnT, persons with renal problems could experience accelerated progress of their kidney disease in the presence of nephrotoxins. In this context, intervention to improve hydration and working conditions for sugarcane harvesters is warranted, and exposure to toxic substances is also important.

Climate change: A critical issue for heat-exposed workers

Even the most optimistic IPCC climate models predict temperature increases of about 2°C in the tropics over the next century and other estimates are even higher. It is also likely that there will be an increase in the incidence, severity and duration of heatwaves (41). It is easy to think that “two degrees isn’t that much” or, “heatwaves are unpleasant but not dangerous”, but both are very real hazards for working populations who are already at the edge or over acceptable limits (53).

Consideration of workers in climate change and health assessments was minimal for many years (35,36,43), but this research adds to other recent evidence (49) that heat-exposed workers are a vulnerable population with specific needs that should be considered as such in climate change adaptation strategies. The idea that climate change is only an environmental or sustainable development issue is changing (6) and after some 20 years of climate change research, occupational health is finally starting to get necessary attention (48,51). For example, the International Labor Organization (ILO) calls for the consideration of social and labor markets in National Adaption Plans for climate change (48).

Moving forward – Achieving protection for sugarcane harvesters: Answers to common questions

Creating safe working conditions for sugarcane harvesters will require a coordinated response from multiple actors: government, researchers, employers, supervisors and harvesters themselves. Sugarcane harvesting is an example of the logistical challenges to achieving protection from heat stress in tropical agricultural work settings. There is currently enough information, technology and policy experience to achieve a safe working situation. It is common, however, for actors to feel overwhelmed by the challenges that exist. Below are some responses to the most common questions posed by those in a position to take action.

How hot is too hot?

Helpful guidelines have been established by the US Military, NIOSH, OSHA,
ACGIH, ISO and state programs in California and Washington (Table 8). For example, the US Army provides guidelines based on WBGT and workload for heat categories 1, 2 (green), 3 (yellow), 4 (red) and 5 (black) and gives work-rest ratios and water intake guidelines for “easy work”, “moderate work” and “hard work”. For example, the work described here would be “yellow”, (requiring 30-30 minutes rest-work ratio and ¾ quarts (approximately .75 L) of water per hour) and some “red” (requiring work-rest ratios of 20-40 minutes and ingestion of ¾ quarts of water per hour) (7).

Once a risk of heat stress has been identified, it is not necessary to have WBGT measured every day to know when and how to intervene. The results of this study clearly demonstrate that there is a risk of heat stress for most of the shift on most days, so basic prevention measures need to be in place every day for sugarcane harvesters. However, there is a need to establish when additional risk for sugarcane harvesters exists, for example, during heatwaves or days in which the temperatures and humidity create particularly dangerous situations for workers.

As a long term goal, it might be possible for Costa Rica to have a heat index reported daily the same way the National Meterological Institute (IMN) gives the ultraviolet index (107) which would allow for more simple decision making to protect workers and the general public. Existing state heat standards in the United States (USA) simply use air temperature (dry temperature) to determine the threshold for action (108–110). This falls short, as it does not take relative humidity nor solar radiation into account, but it easier to monitor than WBGT and therefore more likely to be enforced. OSHA recommends the use of a heat index that accounts for temperature and humidity (111) from reported weather data while NIOSH recommends the use of WBGT-based limits (92).

**How much liquid do sugarcane harvesters need?**

One of the most frustrating and difficult questions for employers, policy makers, researchers and workers is “How much water should be consumed?” Hydration needs indeed vary from individual-to-individual (14) and different guidelines exist for achieving ideal hydration in the workplace. For example, in the United States, no federally enforceable standard exists, but several guidelines have been established. The OSHA “Field Sanitation Standard” (29 C.F.R. 1987 1928.110) recommends water be “readily accessible” in “sufficient amounts” and says employers should encourage workers to “drink water frequently and especially on hot days (112) ” The American Conference of Governmental Industrial Hygienists (ACGIH), OSHA and NIOSH have guidelines that are often used in the United States. NIOSH, ACGIH and OSHA’s recommendations all suggest drinking 250 mL (one cup) of company-provided cool liquid every 15-20 minutes (92).
**Is it possible that harvesters will drink too much water?**

In the quantitative phase of this study, it was common to hear harvesters, managers or other decision makers express concern about drinking too much liquid. This condition, where serum-sodium levels are too low (<130mmol/L) called exertional hyponatremia, is relatively rare but very serious and potentially fatal (5). Low solute (salt) levels in the extracellular and intravascular fluids results in an abnormal gradient causing water to flow into the cells. The resulting swelling can lead to neurological and physiological dysfunction causing symptoms quite similar to heat stroke (5). However, this condition can be prevented by matching water loss to fluid consumption and by rehydrating with fluids containing sufficient sodium or by assuring adequate and timely consumption of food (113).

The results of this study confirm that harvesters should be drinking more water than they currently do, but it is also important to ensure timely food consumption in the field which will prevent exertional hyponatremia and also increase thirst and the drive to consume adequate liquids (14). Levels of salt in the normal diet are likely adequate, but should be further researched to optimize hydration. Salted hydration solutions are recommended for athletes in some cases (5,14), but more research is needed to determine whether it can be achieved without increasing fructose uptake which has not been ruled out as a contributing factor to CKDnT (100).

**Aren’t sugarcane workers accustomed to hot conditions?**

It is true that the human body is incredibly efficient at adapting to new climate conditions and workers who are accustomed to working in hot conditions will be more able to deal with the heat than a person who comes from a cool environment until adaptation has occurred over a process of 5 to 30 days (2,92). However, it is also true that the human body has physiological limits and this study demonstrates that sugarcane harvesters are working near or above those limits. In addition, the body’s defense mechanisms are most effective with low temperature, low humidity and strong breeze (i.e. a low WBGT). Likewise, the body’s ability to dump excess heat depends heavily on evaporative capacity – i.e. how effectively sweat evaporates from the skin to cool the body. The soot-filled clothing (long pants, boots and often two layers of long sleeved shirts) seen with these workers indicate that sweat cannot evaporate effectively.

In addition, in order to effectively adapt to hot conditions, the body needs sufficient water. Acclimatized workers actually need more water because acclimatization increases sweat rate, and therefore increases the need for fluid replacement (14). Finally, this study demonstrated clear signs of heat illness in
harvesters. A person who has suffered heat illness is more susceptible to future heat illness, especially in conditions like sugarcane harvesting where no consideration is given for acclimatization as a part of return-to-work after illness.

How can we afford to meet these recommendations?

The logistics for achieving proper protection from heat stress and dehydration in sugarcane fields are admittedly very challenging. However, the cost of not protecting workers is far higher: as stressed earlier, agricultural workers in many parts of the world die from exertional heat stroke - deaths that are completely preventable. Secondly, the role dehydration and heat stress may play in CKDnT means that the cost of not protecting workers could literally be the contribution to an epidemic causing thousands of deaths and overwhelming the health care systems as is already the case in Central American countries (114,115).

Sugarcane harvesting is by no means the only workplace where creative and determined protection must be implemented to protect workers. In fact, far greater challenges (and perhaps far greater economic costs) have been overcome in some of the most challenging situations on the planet by militaries. For example, the US Military still reports unacceptably high hospitalization rates due to heat stroke, but has been largely successful in reducing heat exhaustion (116), proving that change is possible.

Policy implications

The results of this study demonstrate that there is an urgent need for policies that regulate workplace heat exposure and hydration for sugarcane harvesters. Such policy should also be applied to protect the other at-risk workers in Costa Rica. Furthermore, the need for heat policy among workers is urgent now, but also must be incorporated into longer-term national climate change policies.

Policy making tends to create opposition, and in the case of both climate change and CKDnT, there will be those that argue that more data is needed before taking action. However, the results of this study make it clear that current heat exposure warrants intervention to decrease the risk of heat stress and related negative health outcomes. The changing climate and the epidemic CKDnT are supporting reasons to improve working conditions for sugarcane harvesters. Any policy implemented would need to be evaluated (49) and modified as necessary. Policy-relevant recommendations are made here with the hope of providing a helpful starting point for decision-making in two main areas: 1) current heat and hydration policy for workers and 2) climate change policy.
In both cases, policy could be created at the government level (Costa Rican Ministry of Health and Ministry of Labor and for climate change policy, the Ministry of Environment), supported by international organizations including the WHO-Pan American Health Organization (PAHO), the ILO, and the Board of Ministers of Health from Central America and the Dominican Republic (COMISCA), enforced and promoted by companies and evaluated and potentially modified by researchers. Of particular importance to the policies suggested below will be addressing poverty and the social determinants of health (57,117) and positioning ‘decent work’ at the heart of economic and social policies (48).

**Heat and hydration policy**

Indeed, no Central American country has implemented a heat standard enforceable by law. This problem is not unique to Costa Rica or Central America. For example, in the United States, a heat standard was proposed in 1986 and updated in 2013, but has not been converted into a federally-enforceable document. Nonetheless, there are a number of good models that could be adapted by Costa Rica including NIOSH’s 2013 criteria for a recommended occupational heat standard (92), ACGIH’s guidelines (118), the OSHA Technical Manual (29), US Military guidelines (7), NATA guidelines for athletes (5,14). In addition, the NATA position statement on fluid replacement for athletes provides an example of straight forward language, solutions and mandates for challenging situations with a focus on empowering the heat-exposed person while detailing the responsibilities of the person in charge (14).

Given that practical guidelines already exist, Table 8 summarizes issues of particular importance for Costa Rican sugarcane harvesters that should be included in any attempts to modify existing recommendations in Costa Rica. Like any policy recommendations, the recommendations in the table should be open to scientific debate and modified according to the most recent information available. The table includes recommendations that could be implemented as national policy; however, lack of policy should not stop individual economic sectors or individual companies from taking actions to protect workers.

**Climate change policy**

Costa Rica has made clear efforts to be a leader in climate change policy, particularly in the Central American region (119,120), and could also lead the way creating climate change adaptation policy that reduces worker vulnerability to heat. Related issues include the ability to respond to extreme weather events, particularly heatwaves (48) and productivity loss due to heat (121). The latter could have important economic impacts at the individual, sector and country levels (121).
Finally, any national plans that include adaptation measures should be revised to include working populations since plans may currently focus on protecting populations traditionally vulnerable to heat: the elderly, home bound, mentally ill and children. Adaptation recommendations also need to account for workers who may not have decision-making power in their workplaces and therefore may not be able to comply with commonly-recommended behavioral changes such as rest and water consumption.

Table 8. Policy recommendations of special importance for Costa Rican sugarcane harvesters.

<table>
<thead>
<tr>
<th>Topic</th>
<th>Recommendation</th>
<th>References</th>
<th>Comments relevant for Costa Rican sugarcane harvesters.</th>
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<tbody>
<tr>
<td>Medical screening</td>
<td>Harvesters should receive a no-cost pre-employment physical exam including screening for conditions that could increase susceptibility to heat stress according to NIOSH recommendations.</td>
<td>NIOSH recommends that medical screening and surveillance programs for all workers exposed to heat stress at no cost and no pay-loss to workers including pre-placement, periodic and emergency care by a physician (92).</td>
<td>Harвестers that have worked for the company previously and who demonstrate decreased kidney function should be reassigned to work with a lower metabolic load. Harвестers should also receive post-harvest exams to assure that kidney function does not decrease during the season.</td>
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<tr>
<td>Acclimatization</td>
<td>Acclimatization periods should be mandatory according to the following: - Experienced workers: 50% exposure (Day 1), 60% exposure (Day 2) and 80% exposure (Day 3) - New workers: 20% exposure (Day 1); and maximum 20% increases from the previous day on each following day. - Return to work (When absence is not related to heat illness): 2-3 days acclimatization working up to full exposure.</td>
<td>NIOSH recommends a 3-14 day acclimatization period using the percentages in the previous column (122). OSHA recommends moving from 50% to 100% over a minimum of 5 days workers and return to work (≥2 weeks away) and notes that some workers will require up to 2-3 weeks to fully acclimatize (111).</td>
<td>Acclimatization should apply not only in the first days of the harvest but also for workers who return to work after absence or who start mid-harvest.</td>
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<tr>
<td>Return to work after heat illness</td>
<td>Companies should have a written plan to monitor workers with previous heat illness upon return to work. The individual and his co-workers should be informed to be alert to early signs of future heat illness.</td>
<td>US Military recommendations (7) for those experiencing heat exhaustion symptoms are to rest, cool and dehydrate. If the person does not show improvement within one hour, he should be seen by a physician. US Military personnel who suffer heat stroke require gradual and monitored return to tasks as well medical clearance periodically for a year to determine whether full activity can be resumed (7). NATA recommends that any person suffering heat exhaustion or heat stroke be approved by a physician before returning to activities after recuperation and states that “return to full activity should be gradual and monitored; be aware that patients will likely be more susceptible to future heat-injury” (5).</td>
<td>Symptom data from this study demonstrated that many workers have a likely history of heat illness. These workers will likely be more susceptible to future heat illness.</td>
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<tr>
<td>Temperature or heat index</td>
<td>WBGT or the OSHA Heat index should be used to set limits if possible, but if this is not possible, then temperature potentially be used.</td>
<td>The OSHA heat index takes temperature and humidity into account. Guidelines are available in Spanish (123). NIOSH and ISO recommendations use WBGT (25,92). High WBGT (or temperature) on the previous day and night affect heat illness, even under relatively cool conditions on the day heat illness presents (5,124).</td>
<td>Data provided here is ready for use with WBGT but could be adapted for use with the OSHA heat index. National weather data can be used, but sugarcane companies usually have their own weather stations that could easily be adapted to collect the necessary data. It is important to use extra caution on hot days as well as the day after a hot day.</td>
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<tr>
<td>Hydration</td>
<td>Minimal recommendations:</td>
<td>NIOSH (92), ACGIH (118) and the states of California and Washington have reasonable water recommendations (108,110).</td>
<td>Monitoring of intervention programs to improve hydration could consider the use of urinary USG ≤1.020 pre and post-shift as an indicator of hydration.</td>
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<td></td>
<td>-One cup of cool, palatable and potable company-provided water every 20 minutes.</td>
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<td></td>
<td>-In the absence of other technology, a person could be employed to carry water to harvesters to reduce metabolic load during rest breaks.</td>
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<td>Workers should be protected from pay loss during hydration breaks.</td>
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<td></td>
<td>Employers should assure adequate and frequent consumption of food containing sodium.</td>
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<td>Older workers</td>
<td>Include special attention for workers 50 years and older.</td>
<td>Literature documents that people in their 50s or 60s are more physiologically susceptible to heat illness, even when exceptionally physically fit (122,125–127).</td>
<td>This research included workers up to 63 years old. Older workers are often the most productive and are leaders, especially when the workforce lives together in a labor camp setting. They are an active and productive part of the workforce. Company protocol should take special care to protect workers 50 years and older.</td>
</tr>
<tr>
<td>Education and training</td>
<td>Employers should provide continual education and training to workers based on a written training program. Important content:</td>
<td>NIOSH (122) and OSHA (128) content for training programs is freely available on the internet. Much information is available in Spanish.</td>
<td>One sign of advanced heat illness can be confusion or loss of judgment (129) that can result in a workers resisting advice from co-workers who suggest taking a break (27). Therefore, harvesters and supervisors who know their co-workers well and can recognize signs of unusual behavior are positioned to make life-saving decisions.</td>
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<td>-Early recognition of heat illness(14).</td>
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<td></td>
<td>-Importance of hydration in non-working hours and arriving to work well hydrated (14,93).</td>
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</table>
### General working conditions

Always use a bus instead of a cattle truck to transport workers in order to avoid adding to heat stress exposure.

- Establish work-rest ratios.
- Provide for rest breaks in the shade.
- Assure nutritional needs are met before, during and after the work shift.
- Consider alternative solutions such as backpack-style water bottles.

NIOSH recommends appropriate work-rest ratios for similar metabolic loads (92).

Improvements should be evaluated and improved continuously.

A nutritional guide in Spanish was developed as part of this research and is available upon request.

Workers suggested a number of potential alternative solutions such as backpack hydration systems that were included in technical reports printed in Spanish.

### Mandatory rest breaks

Breaks as a part of work-rest ratios should be mandatory.

OSHA recommends rest breaks during which workers may continue to perform light work such as receiving training (130) US Military (7) and NIOSH (92) have clear guidelines for the percentage of each hour for rest and work according to WBGT temperatures.

Sharpening machetes could be evaluated as an appropriate “rest” activity. Since workers are paid by how much they cut, it is essential that breaks be mandatory and that they not affect worker pay.

### Emergency plan

Companies should have an emergency plan for attending to heat-related emergencies. All supervisors, management and harvesters should be familiar with the plan.

A list of warning signs and symptoms of heat illness and injury and corresponding treatment has been developed by the US Military (Figure 5-1, p. 40 Technical Bulletin) (7) and OSHA (131) The latter is available in Spanish.

Emergency plans should include preventive actions for heatwaves and response plans for negative health outcomes.

### Record keeping

Heat-related cases requiring medical attention or first aid should have a mandatory reporting and record keeping requirement.

California and Washington as well as NIOSH have clear recordkeeping requirements (108,110).

US Military has surveillance suggestions including clinical and case definitions (Section 5-5 p. 44)(7).

Record keeping should include workers treated by company medical personnel as well as (subcontracted) workers treated in local health facilities.
Future research

The results of this study suggest several areas of research that could be helpful for advancing the protection of heat exposed workers. Any advances to validate markers of hydration that are easy to use in workplace settings should be helpful. When it comes to hydration in the workplace, the existing recommendations from the USA outlined here are good starting places, but research must be done to determine the cultural acceptability and feasibility of recommended measures. For example, temperature recommendations by NATA indicate water be offered at 10-15°C to increase consumption (14). Future studies could determine whether this recommendation remains true in Costa Rica with cultural differences around acceptable temperatures.

Cost-analyses of recommended interventions will be essential. Cost-benefit analyses must be calculated for proposed interventions as well the cost of not taking action. The State of Washington has conducted a cost analysis of the state-wide heat standard that accounted for costs and benefits for businesses as well as worker productivity and medical costs (132). This model could perhaps be adapted for Central America.

Future research could also consider the influence of clothing and soot on sweat evaporation. For example, NATA recommends different WBGT limits for athletes wearing shorts and a T-shirt versus other clothing or equipment such as the pads used for American football (5). It would be of use to make WBGT limit values based on typical clothing as well as the soot that likely prevents evaporation of sweat and increases heat absorption due to its color. Such modified limit values could also be extended to other job tasks such as pesticide applicators who must wear rubber protective gear. Understanding the role of temperature and potential environmental toxins, i.e. the potential increased absorption due to increased temperature and to skin wetness from PPE is necessary for designing effective interventions.

Finally, as occupational health researchers, we must view our work not only for present realities, but also in the context of climate change. A recent call on public health professionals to create epidemiologic models that can “accommodate the unusual scale and complexity of the health risks of climate change” (40) is especially applicable to occupational health. One recent model out of Québec has outlined three major research orientations related to climate change and occupational health: 1) acquisition of knowledge on hazards and target populations, 2) epidemiological surveillance and 3) the development of adaptation measures. It provides a model for identifying potentially affected individuals and sectors accounting for the environment and socio-economic contexts as well as prioritizing research needs specific to climate change and occupational health (51).
Conclusions

- Heat exposure is an important occupational health risk for plant and field workers in the sugarcane harvest and non-harvest seasons.

- Sugarcane harvesters do strenuous work in harsh climates and, according to international standards, labor mostly under heat stress conditions.

- Poverty, migrant status, temporary work, living conditions, education level, and lack of jobs in harvester populations increase the vulnerability of sugarcane harvesters to heat-related exposure.

- A large percentage of harvesters are experiencing symptoms of heat exhaustion on a continual basis throughout the harvest season.

- Pre and post-shift urine samples demonstrate evidence of dehydration and signs of kidney injury in sugarcane harvesters.

- There is an urgent need to improve working conditions for sugarcane harvesters through implementation of hydration, shade and work-rest ratios.

- With ongoing climate change, increases in temperature as well as heatwaves are expected and will result in further heat exposures for many working populations including sugarcane harvesters.

- Policies and guidelines to better protect workers from heat stress need to be designed and implemented at multiple levels by multiple actors: government, international organizations, researchers, employers, supervisors and harvesters themselves.
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**To my family:**

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Appendix

The following two documents are included as an example of materials used to communicate findings to the workers who participated in the study:

1. Poster used to explain WBGT

Design by Yolanda Gómez Campos
2. Poster with hydration recommendations

1- Al levantarse
- Tomar el hidratante
- 600 ml de agua

2- En el trabajo
- Tomar mínimo 6 litros de agua

3- Después del trabajo
- Hacer una merienda entre el almuerzo y la cena
- 1 litro de agua

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Design by Yolanda Gómez Campos
3. Document of final results given participants in conjunction with oral presentation of results

RESULTADOS DEL PROYECTO

Exposición a calor extremo en cortadores de caña de azúcar y sus posibles soluciones

El Estudio - ¿Qué hicimos?

Este proyecto se realizó durante 3 zafras, en las cuales estudiábamos el calor, la salud y el trabajo de cortadores de caña, con el fin de entender mejor los efectos del calor en los trabajadores y que efectos podrían existir si las temperaturas aumentan en la zona.

El trabajo es un esfuerzo en conjunto entre la Universidad Nacional (IRET y CEMEDE) y el Instituto Tecnológico de Costa Rica (ESLHA) (ver la última página).

En este informe presentamos los resultados más importantes.

Resultados

Síntomas relacionados con exposición a calor

Según nuestras encuestas, los cortadores de caña reportan más síntomas relacionados con trabajo que se realiza en calor extremo, que otros trabajadores en el Ingenio. Esto es evidencia que la salud se está deteriorando por el trabajo físico e intenso en combinación con el calor extremo.

El trabajo de cortar caña, el calor y el peligro de “estrés térmico”

Cuando los cortadores de la zona de Guanacaste realizan su trabajo, después de las 7:30am su cuerpo puede entrar en un estado de “estrés térmico”. Esto significa que el cuerpo puede tener problemas para mantener su temperatura normal.

Los efectos más comunes pueden ser: dolor de cabeza, boca seca, nauseas y mareo. Si no se trata a tiempo, la persona se puede desmayar o sufrir un golpe de calor.
El Calor

- Durante el estudio, utilizamos una máquina (ver foto) para medir un índice de calor que se llama TGBH. Este índice es un indicador de la temperatura en conjunto con la brisa y la humedad del aire.
- Cuando una persona corta caña, se genera calor en el cuerpo por el movimiento de los músculos.
- Cuando se combina el calor del ambiente y el calor del cuerpo se puede resultar difícil mantener la temperatura normal (37°) del cuerpo. Esta condición se llama “estrés térmico”.
- En las condiciones normales de Guanacaste, un cortador de caña puede estar bajo “estrés térmico después de las 7:45am de la mañana (ver gráfico)

La Hidratación

Dentro del estudios se realizaron muestras de orina y el registro del peso de los cortadores antes y después de la jornada, esto para conocer si la persona está “hidratada” (si la persona tiene suficiente agua en el cuerpo).

Las muestras de orina:

- Las muestras de orina dieron diferentes resultados para cada persona. Dentro de la interpretación de los resultados algunos cortadores tuvieron resultados que caben dentro de lo “normal”, sin embargo otros presentaron indicios de enfermedades o infecciones.
- Algunos cortadores tuvieron reportes de gravedad específica normales, lo cual significa que estaban bien hidratados, pero otros tuvieron una gravedad específica alta, lo cual que indica que estaban deshidratados. (Su orina estaba demasiado concentrado).
- En los cortadores que tuvieron alguna infección o algún problema renal es imposible saber si el cuerpo estaba bien hidratado utilizando la gravedad específica.

El peso:

- Se pesaron a los cortadores antes y después de la jornada para asegurar que no pierden peso por sudor durante la jornada. La mayoría de los cortadores no perdieron peso durante la jornada. Esto es buen señal que los cortadores están tomando suficiente agua, sin embargo es posible que no se pierda peso (o que ganan peso durante la jornada) debido a la retención de líquidos, esto podría ser el resultado del alto consumo de sal.
Las mediciones del Índice TGBH durante un día normal (línea azul) comparado con el TGBH seguro para cortar caña utilizando un esfuerzo máximo (línea roja). Por encima de la línea roja, un cortador de caña va a tener dificultad de mantener su temperatura normal. En Guanacaste, se sobre pasa a este límite a partir de las 7:45 am la mayoría de los días.

Las Recomendaciones Finales

**Hidratación**
- Tomar 600 mL de agua a levantarse (la medida de una botella de agua o coca)
- Tomar 1 Litro de agua para cada hora que labora
- Tomar una bebida hidratante (el paquete de 40 g disuelto en la botella de 750 mL) después de la cuarta hora laborada (aproximadamente 9:00 am)
- Tomar por lo menos un litro de líquido después de llegar al bache y antes de acostarse.
- No espere a sentirse sediento para tomar agua, ya que la sed es el primer signo de deshidratación.
Nutrición

- Comer tres comidas principales y dos meriendas.
- Todos los días comer las siguiente cantidad de porciones:
  - Leche (2)
  - Vegetales (6)
  - Frutas (2)
  - Cereales (14)
  - Carne o proteína (4)
  - Grasa (8 cucharaditas)
  - Azúcar (12 cucharaditas)
- No añadir sal a la comida. Los platos que le sirven ya tienen sal.
- Moderar el consumo de azúcar, a no más de dos cucharaditas en un vaso o 2 cucharaditas en una taza.
- Desayunar y tomar un fresco (preferiblemente de leche) antes de salir a trabajar.

Para más información

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Las recomendaciones para el Ingenio

A los gerentes del Ingenio se están recomendando las siguientes acciones para mejorar la protección de los cortadores frente al estrés térmico:

- Distribuir agua fresca y hidratante durante la jornada.
- Asignar un aguatero a las cuadrillas
- Proveer algún tipo de sombra para descansos
- Promover la rotación de trabajos para que el trabajador no esté trabajando al 100% de esfuerzo máximo durante toda la jornada.
- Utilizar como medio de transporte bus en lugar de camión para proteger a los trabajadores del calor.
- Seguir las indicaciones del informe de nutrición para la hidratación, las comidas y las meriendas.