Performance of selected macroinvertebrate-based biotic indices for rivers draining the Merendon Mountains region of Honduras

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ABSTRACT
Cusuco National Park, a cloud forest park situated in the Merendon Mountains region of Honduras, is home to considerable biodiversity with a very high degree of endemism. Like many other cloud forest parks in Central America, it was declared a protected area not because of its biodiversity, but mainly because of its function in protecting river water quality in the headwaters draining the park. Illegal and authorised forest clearance for agricultural activity such as coffee production and pasture for animals and diffuse inputs from settlements are expected to affect aquatic macroinvertebrate communities and the water quality of the rivers in the park. There is however very limited water quality monitoring, mainly because biological indices such as those in use in Europe and the United States have not been developed in Honduras. A research project based on macroinvertebrates was initiated in 2009 to develop a water quality index for the area. Sampling was undertaken between June and August 2009 and set out to study minimally disturbed upper catchments of reference rivers. This paper evaluates the performance of several indices. A version of the ASPT based on the BMWP calibrated for Costa Rica (BMWP(CR)) performed best.

KEY WORDS
Biomonitoring, Honduras, macroinvertebrates, neotropics, upland stream, water quality

RESUMEN
El Parque Nacional de Cusuco es un Parque ocupado en su mayor parte por un bosque de niebla que se localiza en la región de las montañas Merendon en Honduras y que alberga una considerable biodiversidad con un alto grado de endemismos. No obstante, este Parque Nacional, como muchos otros parques de bosque de niebla en Centro América, fue declarado Área protegida no por su biodiversidad, sino principalmente por su función en la protección de la calidad de las aguas fluviales de las cabeceras de las cuencas de drenaje del parque, al ser la fuente de agua potable para varias áreas urbanas de gran tamaño entre las que se incluye San Pedro Sula. Se espera que clareos de bosque, tanto ilegales como autorizados, para actividades agrícolas como la producción de café y pasto para los animales, y el aporte difuso desde los asentamientos, afecten a las comunidades de macroinvertebrados acuáticos y a la calidad del agua de los ríos del parque. Sin embargo, hay una monitorización muy limitada de la calidad del agua, debido principalmente a que los índicos biológicos como aquellos que se usan en Europa y en los Estados Unidos entre otros, no han sido desarrollados en Honduras. En 2009 se inició un proyecto de investigación con el fin de desarrollar un índice de calidad de agua basado en macroinvertebrados. Muestreo se llevó a cabo entre junio y agosto de 2009, y en ella se propuso muestrear captaciones superiores mínimamente alteradas de ríos de referencia. Este artículo evalúa el resultado (rendimiento) de una gama de índices de calidad de agua existentes, basados en macroinvertebrados bajo condiciones de referencia. Estos emplazamientos están en bosques primarios con poca o ninguna evidencia de influencias antropogénicas actuales o históricas. Dada la falta de influencias antropogénicas en estos lugares, se espera que varios índices devuelvan resultados que indiquen un alto estatus. Los factores que causan la desviación de los resultados esperados son examinados. Una versión del ASPT basado en el BMWP calibrado para Costa Rica (BMWP(CR)) es la que da mejores resultados.

PALABRAS CLAVE
Biomonitoreo, Honduras, macroinvertebrados, neotrópico, corriente de la montaña, calidad del agua.

There is a limited body of research on freshwater systems in tropical regions. Efforts to build on existing knowledge are hampered by political and financial considerations as well as issues of access to papers in various disparate journals and so called 'grey literature' (Jackson & Sweeney, 1995a; Springer, 1998). Furthermore, a lack of taxonomic expertise and local reference collections in the neotropics, an obligatory first step for community ecological studies, presents certain difficulties (Springer, 1998). However, neotropical streams are receiving increasing attention from researchers due to their considerable ecological and economic importance (Covich, 1988).

Most of our current models for stream nutrient dynamics, decomposition, and regulation of community structure have been derived from extensive and detailed research on lotic systems in temperate zones (Wantzen, Ramírez & Winemiller, 2006). To what extent these apply to neotropical systems is unclear. In terms of anthropogenic pressures temperate streams tend most commonly to be affected by channel modification and diffuse pollution (Wantzen et al., 2006) among others. Diffuse pollution from agriculture has also been documented in the neotropics (Castillo et al., 2006) and like most areas neotropical streams are often affected by airborne contaminants (Standley & Sweeney, 1995). However, Central American streams are more commonly affected by point sources such as municipal sewage and localised sediment inputs usually associated with land-use change (Biggs, Dunne & Martinelli, 2004; Mol & Ouboter, 2004; Baptista et al., 2007).

A basic requirement for the management of pollution pressure is the accurate assessment and monitoring of water quality, something that can be conducted using direct physico-chemical measurements or indirect measurements (measuring the effect of a pressure on an organism, group of organisms or some aspect of these) (Rosenberg & Resh 1993). Chemical monitoring can miss or underestimate even recent pollution events unless continuous, and therefore expensive, monitoring is employed (Rosenberg & Resh, 1993) and should ideally only be used in support of ecological assessment. Therefore, the use of biotic indices based on macroinvertebrate assemblages is now the main approach in the United States (USEPA, 1972; Hilsenhoff, 1988; Rosenberg & Resh, 1996; Barbour et al., 1999) and Europe (Armitage et al., 1983; Alba-Tercedor & Sanchez-Ortega, 1988; WFD, 2000; AQEM-consortium, 2002) to assess water quality. However, water quality monitoring in the neotropics is still largely limited to chemical/physical parameters despite the fact that biological methods offer more practical advantages as they can overcome the logistical difficulties of traditional chemical-physical surveys and are advantageous from an economic point of view (Fenoglio, Badino & Bona, 2002, Fenoglio, 2005). In Central America and in particular in countries such as Honduras and Costa Rica there is large demand for rapid bioassessment methods and metrics (Fenoglio et al., 2002). In this respect the use of macroinvertebrates seems advantageous as taxonomic and ecological information on these groups is better known in the tropics than other biota such as algae (Jackson & Sweeney, 1995b).

Before embarking on the development of new biotic indices for a region it is useful to undertake an assessment of the performance of existing systems and in what respect they are applicable to the new biogeographic region. Although most of the macroinvertebrate families used in biotic indices from the more northern regions are also found in the tropics, they may not necessarily occupy the same niche or have the same functional role as in temperate regions, and furthermore, they may not be similarly sensitive to water quality deterioration. The present study tested how well biotic indices from other biogeographic regions measured water quality in upland rivers/streams in a mountainous region of Honduras where there is little or no anthropogenic inputs from land-use activities. It is common practice to perform initial testing of indices in unpolluted conditions (Armitage et al., 1983) and this approach can be particularly useful when working in poorly studied areas where natural environmental gradients may confound interpretation of anthropogenic effects. We compared water quality classifications for each index based on two factors, firstly how many sites were indicated to be of high quality and secondly how many local invertebrate taxa were taken into account by the given index.

METHODOLOGY

Site Selection

The data were collected from El Parque Nacional Cusuco in the Merendon Mountains region of northern Honduras (15°29'41,028"N and 88°12'48,4554"W) from June to August 2009. Fifteen minimally impacted sites were chosen across seven catchments using a GIS model with sites being chosen on the basis of hydromorphological characteristics. These typing characteristics included catchment size, geology and slope (Fig. 1).

Sampling protocol

Three replicate, 2-minute macroinvertebrate kick samples were taken with a standard pond net (1000µm mesh) at each site using a multi-habitat sampling procedure with time in each habitat spent proportional to the frequency of its occurrence at the site (Wright, 1995; Wright,

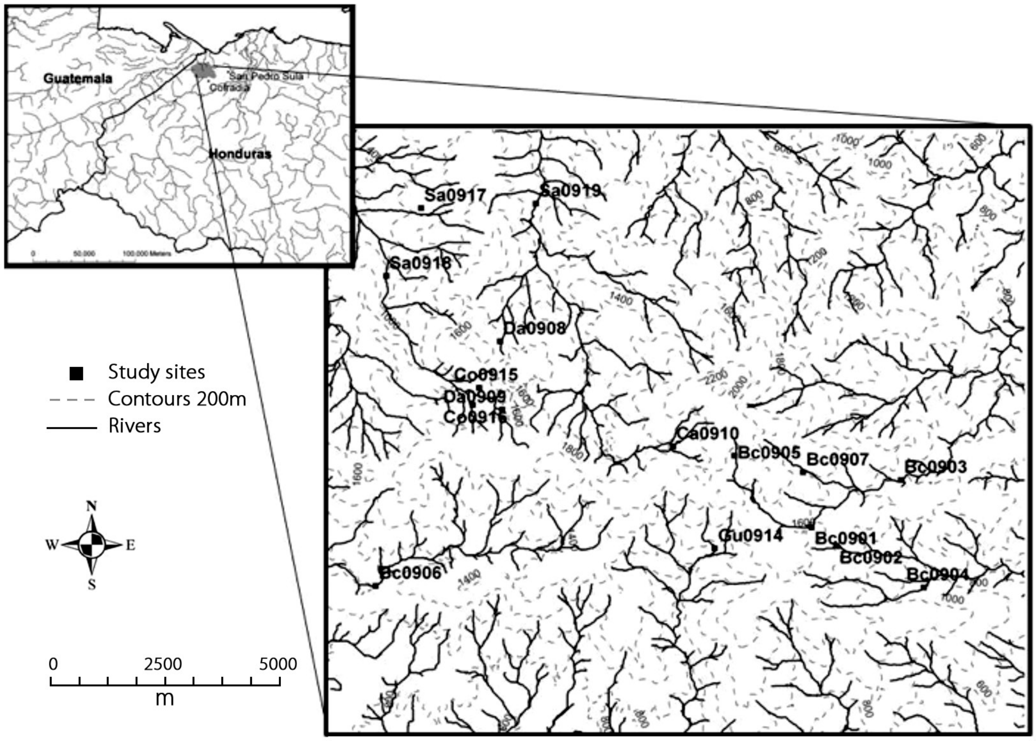

FIG. 1. Map showing location of el Parque Nacional Cusuco in Honduras and sampling site locations.

Furse & Moss, 1998). Samples were returned to the nearest camp to be live sorted and the contained macroinvertebrates were preserved in 70% ethanol. Individuals smaller than 1000µm may have been lost but this is a standard methodology often used in routine bioassessment (Wallace, Grubaugh & Whiles, 1996; Whiles et al., 2000; Dickens & Graham, 2002; Callanan, Baars & Kelly-Quinn, 2008). Specimens were returned to the laboratory in University College Dublin and identified to family level, this being the taxonomic level used in most bioassessment metrics.

Biotic Indices Applied

Indices calculated included the Biological Monitoring Working Party (BMWP) (Armitage et al., 1983) and its associated Average Score Per Taxon (ASPT), as well as the version calibrated for Costa Rica (Ministerio del Ambiente y Energía, 2006) and the Spanish version calibrated for the Iberian peninsula (IBMWP and IASPT) (Alba-Tercedor & Sanchez-Ortega, 1988). The South African Scoring System (SASS) (Chutter, 1994; Dickens & Graham, 2002) and its associated ASPT were calculated as well as Hilsenhoff Family Level Biotic Index (FBI) (Hilsenhoff, 1988). The BMWP was developed in Britain across a wide range of river types including smaller upland streams and has been shown to be reliable across a wide altitudinal gradient (Armitage et al., 1983; Zamora-Muñoz et al., 1995), the system assigns each family a score between one and ten, based on its sensitivity to organic pollutants. Pollution-sensitive families have high scores and pollution-tolerant ones low scores. No adjustment is made to allow for relative abundances of the various families (Armitage et al., 1983; Walley & Hawkes, 1997). The ASPT is simply the BMWP score divided by the number of scoring taxa (Armitage et al., 1983). The SASS was first developed by Chutter and is now on its 5th iteration (Chutter, 1994). It is based on the BMWP system with each family assigned a score the sum of these giving the SASS. Furthermore, the number of scoring families (NTaxa) and an ASPT are calculated. It is a combination of the SASS and the ASPT scores which indicates the quality of the river. The Hilsenhoff or FBI (Family-level Biotic Index) is calculated by multiplying the abundance of each indicator family by its tolerance value, summing the products and dividing by the total number of macroinvertebrates in the sample. This index does not include families from the Hemiptera or Coleoptera (except Elmidae and Dryopidae)

(Hilsenhoff, 1988). The index cut-off levels used for high, good and moderate water quality for the various biotic indices are given in Table 1.

One-way ANOVA was performed to compare index values between sites. As all sites are considered to be minimally impacted scores calculated by the various indices are not expected to differ significantly between sites.

ASPT(CR) was also calculated for a further six sites within the park which are characterised by high levels of iron either in solution or as precipitate. These high iron levels occur naturally and are thought to be the result of exposed geology resulting from landslides. The ASPT(CR) scores for these sites were compared to six other sites within the same altitudinal range using one-way ANOVA.

RESULTS

A total of 60 families were recorded across all fifteen sites with an average of 25 families per site. Representatives from most invertebrate groups were recorded, however a single amphipod family represented the Crustacea and both Mollusca and Arachnida were absent. A list of those taxa found during the study including those not used in the calculation of the various metrics is presented in Table 2. The original BMWP had the greatest number of un-scored taxa at 31 with the Costa Rican BMWP having the lowest number un-scored at nine. This included a minimum of three trichopteran families (BMWP(CR) and IBMWP indices) and a maximum of eight trichopteran

TABLE 1
Values used to assign various index scores to water quality classes

	IBMWP/ BMWP(CR)	ASPT	Hilsenhoff FBI	SASS	
				SASS	ASPT
High	>100	>6	0-3,75	>100	>6
Good	61-100	4-5	3,76-5,5	<100	>6
Moderate	36-60	3-4	5,51-6,5	50-100	<6
Poor	16-35	2--3	6,51-8,5	<50	variable
Bad	<15	1-2	8,5-10		

TABLE 2
List of Taxa used in the calculation of each biotic index.

Taxon	BMWP	IBMWP	BMWP(CR)	Hilsenhoff	SASS
Hydropsychidae					
Leptoceridae					
Hydrobiosidae	X	X		X	X
Philopotamidae	X				
Lepidostomatidae					
Calamoceratidae	X	X		X	
Ecnomidae	X			X	
Brachycentridae	X		X		X
Glossosomatidae	X				
Rhyacophilidae			X		X
Polycentropodidae					

X denotes that the taxon was not included.

TABLE 2 (Continued)
List of Taxa used in the calculation of each biotic index.

Taxon	BMWP	IBMWP	BMWP(CR)	Hilsenhoff	SASS
Apataniidae	X	X	X	X	X
Odontoceridae					X
Limnephilidae					X
Hydroptilidae	X				
Notonectidae				X	
Veliidae	X		X	X	
Naucoridae				X	
Gerridae			X	X	
Belostomatidae	X	X		X	
Corixidae				X	
Elmidae					
Amphizoidae	X	X	X	X	X
Psephenidae	X	X		X	
Dryopidae					
Hydrophilidae				X	
Lampyridae	X	X		X	X
Scirtidae	X	X		X	X
Dytiscidae				X	
Gyrinidae				X	
Hydraenidae	X	X		X	
Tricorythidae	X	X			
Leptophlebiidae					
Heptageniidae					
Baetidae					
Perlidae					
Chironomidae					
Simuliidae	X	X			
Ceratopogonidae	X				
Tipulidae					
Blephariceridae	X				
Ephydridae	X				
Athericidae	X				
Empididae	X				
Dolichopodidae	X				X
Gomphidae					X
Coenagrionidae	X				
Libellulidae					X
Calopterygidae	X				

X denotes that the taxon was not included.

TABLE 2 (Continued)
List of Taxa used in the calculation of each biotic index.

Taxon	BMWP	IBMWP	BMWP(CR)	Hilsenhoff	SASS
Platystictidae	X	X		X	X
Lestidae					
Aeshnidae					X
Cordulegastridae					X
Corduliidae					
Corydalidae	X	X			X
Neargyractis	X	X	X	X	X
Crambidae	X	X	X	X	X
Petrophila	X	X	X	X	X
Amphipoda	X	X			
Total	31	17	9	22	19

X denotes that the taxon was not included.

families in the case of British BMWP. However the majority of these were encountered infrequently and in low numbers. Table 3 lists those taxa which occurred in more than five sites and had on average at least one individual per site but were not scored by the various biotic indices. This includes only seven families with none of the applied indices having more than four non-scoring families.

BMWP and ASPT

The BMWP scores fell between 50,3 and 121 and the ASPT values between 6,45 and 7,44. All ASPT values exceeded 6,0 (Table 4), a value generally considered to represent high quality (Chutter, 1994; Chapman, 1996; Callanan et al., 2008). The IBMWP allocated 33,3% (5 sites) of sites to high quality, 46,6% (7 sites) to good and the remaining 20% (3 sites) to moderate quality (Table 4) (range 51,6 to 127) while the IASPT assigned 100% (15 sites) of sites to high status (range 6,27 to 7,30) (Table 4). Finally the Costa Rican version of BMWP assigned 46,6% (7 sites) of sites to high status, 46,6% (7 sites) of sites to good status and the remaining site (6,6%) to moderate status (range 61 to 141,6) while the ASPT(CR) classified 100% (15 sites) of sites as high status (range 6,11 to 6,77).

Hilsenhoff (FBI) Index

The Hilsenhoff index categorises scores in a seven point scale ranging from excellent (less than 3,75) to very poor (7,26-10). Four of these classes have been combined into two for the purposes of comparison, Hilsenhoff's very good and good classes have been combined and are here referred to as good and in addition Hilsenhoff's fair and fairly poor combined and referred to as moderate, ranges used can be seen in Table 1. Here only sites scoring below 3,75 (lower scores indicate higher quality in the Hilsenhoff index) were considered to be of high quality as above this value the index allows for slight organic impact. Scores achieved by the sites fell between 2,82 and 3,87. The Hilsenhoff index indicated that 80% (12 sites) of sites were of high quality with the remaining three sites classified as good (Table 4).

SASS (South African Scoring System)

Sites are assigned to quality classes according to Chutter (1994) based on both the SASS score and ASPT. For example a site was considered of high quality if SASS was above 100 and ASPT above 6, if one of these fell below these levels it was considered good quality and if both were below these values the site was considered moderate (Table 1). Of the 15 sites 13,3% (2 sites) were of high quality and the remaining sites were classified as good quality (Table 4).

Statistical Analysis

One-way ANOVAs were carried out to compare calculated index values between sites. All indices based on the BMWP (BMWP, BMWP(CR), IBMWP and SASS) showed significant differences between sites ($F_{14, 30}$= 4,352, p = 0,00, $F_{14, 30}$ = 5,116, p = 0,00, $F_{14, 30}$ = 4,285, p = 0,00, $F_{14, 30}$ = 7,013,

TABLE 3
Non-scoring taxa occurring in more than 5 sites at an average of >1 individual per site.

Taxon name	BMWP	IBMWP	BMWP (CR)	Hilsenhoff	SASS
Odontoceridae					X
Naucoridae				X	
Psephanidae	X	X		X	
Gomphidae					X
Coenagrionidae	X				
Platystictidae	X	X		X	X
Corydalidae	X	X			X
Total	4	3	0	3	4

X donates that this taxon was not used in calculation of the given index.

TABLE 4
Percentage of sites assigned to high, good or moderate water quality by the selected biotic indices.

Index	High	Good	Moderate
ASPT	100	0	0
BMWP(CR)	46,6	46,6	6,6
ASPT(CR)	100	0	0
IBMWP	33,3	46,6	20
IASPT	100	0	0
SASS/ASPT	13,3	86,6	0
Hilsenhoff (FBI)	80	20	0

p = 0,00, respectively). These differences lay between several relatively low scoring sites (including sites 2, 9, 19 and in particular site 17 which was assigned particularly low scores in all BMWP based indices) and 3 sites which were generally assigned very high scores (1, 6 and 16).

In contrast , while 3 of the sites failed to be rated as high quality according to the Hilsenhoff (FBI) index the scores did not vary significantly between sites ($F_{14, 30}$= 1,496, p = 0,172). No significant differences were found between values calculated using the various ASPT indices except for ASPT(SASS) ($F_{14, 30}$ = 4,230, p = 0,00). The significant difference can be attributed to one site (site 2) which while scoring significantly lower than several other sites still lay over the threshold for high quality according to the SASS index.

When naturally iron enriched sites were compared with six unenriched sites in a similar altitudinal range ASPT(CR) scores for the six iron enriched sites were significantly lower than the unenriched sites ($F_{1, 34}$= 24,168, p= 0,00). All six sites were classified as at least good quality by the ASPT(CR) index with one site reaching high quality.

DISCUSSION

This study assessed the performance of various water quality indices applied to headwater streams in Cusuco National Park, Honduras. While almost no stream in Central America will be completely devoid of anthropogenic influence most notably airborne contamination, those selected were in catchments with no or minimal human land-use disturbance. Therefore, all sites used in the study were considered to represent reference condition. Generally the selected indices performed quite well. Ideally an index would score all sites as high quality and leave no widely occurring taxa unscored. If several taxa are not included in the calculation of the index it may limit the general applicability of the index across rivers of varying typology. In general, the ASPT indices performed much better than the BMWP indices with scores tending to be higher. ASPT scores also tended to be much more stable with ANOVA analysis showing no significant differences between sites with the exception of the SASS version.

In the SASS system quality classes are not assigned separately for SASS(BMWP) and ASPT but are based on both. For example the criteria for high quality status are that sites must reach an SASS(BMWP) score of ≥100 and an ASPT of ≥6. In the present study while the ASPT(SASS) scores did vary significantly between sites the minimum score was 6,07, therefore the variation in quality class between sites was due to the BMWP component of the SASS. The Costa Rican ASPT system was quite effective, this is not surprising as this was calibrated in Central America and had the lowest number of non-scoring families at nine. Three of these were tricopteran families (Apataniidae, Brachycentridae and Rhyacophilidae) taxa which generally tend to be sensitive to various pressures (Bernard, Neil & Rowe, 1990; Vuori, 1996; Maret et al., 2003; Menetrey et al., 2008). However, none of these taxa left scoreless by the Costa Rican BMWP was either widespread or present in large numbers and so would not be considered important as indicators. The IASPT also performed relatively well, again this metric left relatively few families scoreless (17) which probably contributed to its good performance, of these three occurred widely (Table 3) including a beetle (Psephenidae) and a damselfly (Platystictidae) both of which are considered relatively sensitive by the other indices. Fenoglio (2005) found that the IBMWP index rated all sites as excellent quality, however in that study some family scores were corrected using those from the Hilsenhoff index. These corrections were not performed in the present study. ASPT has been shown to be relatively robust in other studies (Lorenz et al., 2004, Sandin & Hering, 2004; Callanan et al., 2008). This would seem to be confirmed by the present study with all ASPT systems performing well, even when the corresponding BMWP was not so robust.

The Hilsenhoff family level biotic index assigned 80% (12) of sites to high status and the remainder to good status. While this metric left 22 of the families identified without scores only three of these were widespread, two of which (Psephenidae and Platystictidae) would generally be considered sensitive with the third (Naucoridae) being generally considered relatively tolerant. Those sites failing to reach high status scored very close to the good/high boundary. The fact that this metric takes account of abundance probably explains why these sites failed to reach high status. These are upland sites and while they tend to have high scoring families they are not necessarily present in large numbers and the 100 individuals required for the Hilsenhoff standard methodology were not always obtained.

While most of the metrics considered performed reasonably well, overall the Costa Rican ASPT tended to exhibit least variation between sites and showed the most potential for water quality assessment in this region due to its high rating of most sites and that fact that none of the taxa occurring in more than 5 sites was unscored. However, one needs to consider whether adjustment of scores for local conditions in Cucuso, as undertaken by Fenoglio (2005) in Guinope, would produce a more robust tool for the upland streams in the Merendon Mountains region. This can be best achieved by examination of the macroinvertebrate communities across a gradient of pollution, a task which is currently underway by the authors through experimentation as impacted sites cannot be found/accessed within the altitudinal range of the reference sites.

When applied to naturally iron enriched sites in all but one case the ASPT(CR) failed to assign these sites to high status. Of these sites most contained large quantities of iron precipitate, this precipitate tended to deposit on the bed and under rocks creating a relatively simple habitat similar to a heavily silted river. This resulted in low invertebrate abundance. This is a clear indication that these sites, in particular those with high levels of precipitate, must be treated as a separate typology and more appropriate quality class boundaries applied.

In developing countries there is a clear need for rapid and inexpensive tools to assess water quality (Ongley, 1998; Pesce & Wunderlin, 2000). The use of already existing biotic indices would hold obvious advantages as they could be employed quickly and without the costs associated with the development of a novel index. The results of the present study are encouraging and suggest that with minor amendments a range of existing indices, particularly those based on ASPT, can be quickly adapted to areas such as Honduras.

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