

A review of tropical dry forest ecosystem service research in the Caribbean – gaps and policy-implications

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2 A review of tropical dry forest ecosystem service research in the Caribbean – gaps and
3 policy-implications

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19 **Abstract**

20 Tropical dry forests (TDFs) are globally threatened, yet remain poorly studied. In the
21 Caribbean, the most biodiverse of island biodiversity hotspots, TDFs have structural
22 properties distinct from the Neotropical mainland and are important to local communities
23 for ecosystem services. We undertook a systematic review (n = 186) on the ecosystem
24 services literature of Caribbean TDF. Only 19.89% qualified for inclusion, with the majority
25 (43.24%) from grey literature. Research on supporting services (31.14%), particularly
26 primary production was predominant. Most studies (70.97%) took a biophysical perspective
27 and quantification often focused on the supply of ecosystem services (43.00%), while
28 measurement of wellbeing benefits were uncommon. Geographic coverage of all studies
29 was patchy originating from only nine of 28 independent countries and dependent
30 territories. Our findings highlight a lack of research, while accentuating the value of grey
31 literature in quantifying ecosystem services. Of particular concern, are gaps in water- and
32 air-related services and the importance of TDF to human health. To move from biophysical
33 assessments to a broader portfolio of ecosystem services valuation studies, research on
34 Caribbean TDF should be collaborative and strategic. Such gaps and research biases suggest
35 key opportunities for evidence-led policy-making. These lessons are of relevance for
36 mainstreaming ecosystem services into decision-making in Small Island Developing States.

37 **Keywords:** Caribbean, dry forest, ecosystem services, economic value, natural capital, Small
38 Island Developing States

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44 1. Introduction

45 Mainstreaming natural capital requires both biophysical quantification and socioeconomic
46 and political contextualisation of assigned value (Daily et al., 2011; Costanza et al., 2017).
47 However, the value of natural capital for provision of ecosystem services has not been
48 consistently translated into national-level decision-making (Guerry et al., 2015), in part due
49 to weak links between policy and ecosystem services science (Weichselgartner and
50 Kasperson, 2010; Perrings et al., 2011; Waite et al., 2015) and also the inconsistent quality
51 of this science (Seppelt et al., 2011). Changing this status-quo demands reflection on current
52 progress in ecosystem services research, through the lens of policy-making (Rosenthal et al.,
53 2015). Such a review of current progress in understanding of ecosystem services
54 strengthens the effectiveness of this scientific foundation (Tallis et al., 2012; Balvanera et
55 al., 2017), enabling the identification of knowledge gaps and aiding in the development of a
56 policy-relevant **sensu** (Rosenthal et al., 2015) approach to conservation of these services.

57 Tropical dry forests (TDFs) are among the most globally threatened ecosystems (Murphy
58 and Lugo, 1986; Sánchez-Azofeifa and Portillo-Quintero, 2011; Sunderland et al., 2015;
59 Banda et al., 2016) and remain underrepresented in terms of both research and protection
60 (Sánchez-Azofeifa et al., 2005b; Miles et al., 2006; Sunderland et al., 2015). TDFs provide
61 diverse ecosystem services, including carbon sequestration, water regulation, and erosion
62 control (Maass et al., 2005; Balvanera et al., 2011; Portillo-Quintero et al., 2015; Calvo-
63 Rodriguez et al., 2017) as well as the provision of food, fuel and tourism opportunities
64 (Dunkley, 1992; van Beukering et al., 2014; Peh et al., 2015). While ecosystem services of
65 TDF are increasingly being studied, individual studies are often local or regional in scale
66 (Maass et al., 2005; Calvo-Rodriguez et al., 2017; Quijas et al., 2019), leaving large gaps in
67 our knowledge at a national level (Quijas et al., 2019). Indeed, large-scale patterns in
68 ecosystem services do not always scale to regional or local processes (Malinga et al., 2015).
69 This is of concern, given the wide variation in TDF composition, structure and functioning
70 and the vastly divergent response to anthropogenic and natural disturbance across its
71 distribution (Pulla et al., 2015; Banda et al., 2016).

72 More than half of all TDFs are found in the Neotropics, with over 9% of these TDFs found in
73 the insular Caribbean (Portillo-Quintero and Sánchez-Azofeifa, 2010); the Caribbean covers
74 0.5% of total Neotropical land area, thus makes a disproportionate contribution to TDF
75 distribution. Despite this limited landmass, the Caribbean's native forests hosts 2.5% of the
76 world's endemic plants (Myers, 2001) and is a key biodiversity hotspot (Sloan et al., 2014).
77 On these small tropical islands, topography and geomorphology influences their climate and
78 in turn, the distribution of forest formations (Lugo et al., 1981). Dry forests in the insular
79 Caribbean are floristically and structurally distinct from those of continental systems,
80 including characteristics such as high endemism and shorter stature (Murphy and Lugo,
81 1995; Banda et al., 2016). In addition, this region's TDFs includes unique transition zones
82 between continental, West Indian, endemic and pan-tropical/Caribbean floristic elements
83 (Oatham and Boodram, 2006a) and unlike the mainland, species richness and endemism in
84 Antillean TDFs is at least equal to, if not higher than moist forest (Gentry, 1992; Banda et al.,
85 2016). Yet, these unique TDFs are often overlooked in global studies of forest ecosystems
86 (e.g. Dexter et al., 2015) and further, Caribbean terrestrial ecosystem services remain poorly
87 documented (Calvo-Rodriguez et al., 2017).

88 As Small Island Developing States (SIDS), the Caribbean islands have comparatively small
89 landmasses, high concentration of human populations and agriculture in lowland coastal
90 areas where TDFs occur (Portillo-Quintero and Sánchez-Azofeifa, 2010). Additionally these
91 SIDS display a high susceptibility to invasive alien species (IAS) (Lugo et al., 2012) and
92 economic reliance on tourism (Teelucksingh et al., 2013) and forest products (Wilkie et al.,
93 2002). The unique characteristics of islands demands particular attention in relation to the
94 management of ecosystem services (Balzan et al., 2018). Across the Caribbean,
95 environmental management is hindered by complex land tenure due to historical legacy,
96 weak governance and cultural drivers and in many islands, the lowland areas are dominated
97 by private land ownership (Griffith-Charles, 2010). This means that both agriculture and
98 tourism development encroach on the low-lying dry forests (Walters, 2016; Mycoo et al.,
99 2017) and with these losses, the degradation of ecosystem services. These patterns of
100 threat and degradation have meant that the Caribbean has lost 66% of its original TDF, with
101 over 80% of the remaining TDFs in the region highly fragmented (Portillo-Quintero and

102 Sánchez-Azofeifa, 2010). These insular drivers of anthropogenic land cover change differ in
103 relative importance when compared with continental TDFs, with conversion of TDFs for
104 tourism and invasion by exotic species, being of particular importance for insular Caribbean
105 TDFs (Sánchez-Azofeifa and Portillo-Quintero, 2011). Yet across the region, socio-economic
106 reliance on intact TDF habitats is high and local communities place substantial value on
107 these forests (e.g. van Beukering and Wolfs, 2012), highlighting a potential disconnect
108 between perceptions of value and realised land use.

109 There is growing interest in the benefits of environmental valuation in the Caribbean (e.g.
110 TEEB Caribbean Netherlands, 2014; Girvan, 2015). The Caribbean is the third most
111 populated of all the biodiversity hotspots, with an average human population density of
112 over 170 km⁻², which in many islands continues to grow (Williams, 2013). Thus, it is to the
113 governments' advantage to harness the islands' natural capital in their national accounting,
114 to benefit this social capital. However, as elsewhere, this interest has not widely translated
115 into decision-making and better protection for natural environments (Waite et al., 2015).
116 Policy makers are challenged to resolve the conflict between protecting natural habitat and
117 advancing economic development of their growing populations, complicated by patterns in
118 land tenure that are the source of much uncertainty and conflict on the islands (Nelson,
119 2018). Valuing ecosystem services in the Caribbean therefore demands specific attention,
120 given the complex socio-cultural, economic and political issues surrounding conservation
121 decision-making in this biodiversity hotspot.

122 Importantly, the continuing degradation of forests and increasing threat of climate change
123 to Caribbean SIDS (Nurse et al., 2014) and, the gap in policy analysis identified for Caribbean
124 TDFs (Blackie et al., 2014), presents an urgent need for an assessment of current
125 understanding of TDF ecosystem services, to inform decision-making. Here, we present a
126 systematic review of the literature on TDF ecosystem services in the Caribbean SIDS
127 biodiversity hotspot. Specifically, we reviewed the literature in order to (1) evaluate the
128 current state of ecosystem service research for Caribbean TDF, (2) assess geographical and
129 methodological patterns in this research and (3) identify knowledge gaps. We used these
130 results to inform a discussion of the opportunities for bridging these gaps in knowledge and
131 making these findings more relevant to policy practitioners.

132 2. Methods

133 2.1. Definitions

134 Historically, the definition of TDFs has been highly variable (Murphy and Lugo, 1995; Miles
135 et al., 2006; Portillo-Quintero and Sánchez-Azofeifa, 2010; Sunderland et al., 2015),
136 however, pronounced rainfall seasonality underpins all these definitions. Specifically, TDFs
137 are defined by a distinct dry period lasting two to eight months (Murphy and Lugo, 1986).
138 No systematic, detailed vegetation classification system currently covers the entirety of the
139 insular Caribbean, since many do not provide the resolution required to be useful at a local
140 scale (Miles et al., 2006). Here, we follow Miles et al. (2006) and define Caribbean TDFs as
141 insular Caribbean forests with greater than 40% tree cover, and which fall within Olson et
142 al.'s (2001) tropical and subtropical dry broad-leaved forest biome. This definitional
143 approach allows for comparison of TDFs within and outside the region, given the wide usage
144 of Olson et al. (2001) and the FAO definition of closed forests (FAO, 2001; Miles et al., 2006).
145 We define ecosystem services categories according to the Millennium Ecosystem
146 Assessment (MEA) (Alcamo and et al., 2003) and include all four categories, supporting,
147 regulating, provisioning, and cultural, in this review (see Table S1 for definitions). Here, the
148 insular Caribbean was defined as the 13 independent states and 15 dependent territories
149 within the Caribbean Sea, including the Bahamas and Trinidad and Tobago (Fig. S1).

150 2.2. Systematic Review

151 The review methodology was guided by the Guidelines for Systematic Review and Evidence
152 Synthesis in Environmental Management (Collaboration for Environmental Evidence, 2013).
153 This systematic review was defined as a specified search methodology that included at least
154 two databases, which identified and reviewed all publications that addressed the study
155 aims. Boolean searches relevant to each question, were conducted of literature archived
156 over the period 1997 to 2016, in ISI Web of Knowledge for combinations of the phrases
157 "Caribbean", "dry forest", "ecosystem", "ecosystem services". A search was also performed
158 using google.com, scholar.google.com and google.books.com with the first 100 pdfs or word
159 documents examined for their inclusion suitability. In addition, grey literature databases
160 were searched since this is an important source of data omitted from previous reviews of ES

161 in the region (Calvo-Rodriguez et al., 2017). These databases included Treesearch, the US
162 Forest Service Research Publications website, the Food and Agriculture Organisation (FAO)
163 Document Repository, the United Nations Convention to Combat Desertification (UNCCD)
164 documents centre and the Regional Clearinghouse Database of the Caribbean Community
165 Climate Change Centre (CCCCC). The above search terms were used to search these
166 databases, or a subset of the terms where appropriate, such as when Boolean operators
167 were not accepted. Additional literature was also identified through in-text citations of
168 search results, and subsequently sourced wherever possible. For study feasibility, searches
169 were only performed in English. While we recognise that our review cannot be considered
170 exhaustive, we consider that it represents significant coverage of the available literature,
171 given that 64% of the 28 independent states and dependent territories in the insular
172 Caribbean have English as an official language and much research originating from non-
173 English-speaking islands is published in English.

174 We selected for inclusion in the review only the studies that:

- 175 • Focused on regional, local or national TDF in the insular Caribbean.
- 176 • Used the term 'ecosystem services' explicitly or, alternatively, described at least one
177 component of supporting, regulating, provisioning or cultural ecosystem services in
178 tropical dry forest.
- 179 • Presented a quantitative or qualitative assessment of a given ecosystem service
180 component
- 181 • Had a full text available in English

182 Studies were then classified according to the following features:

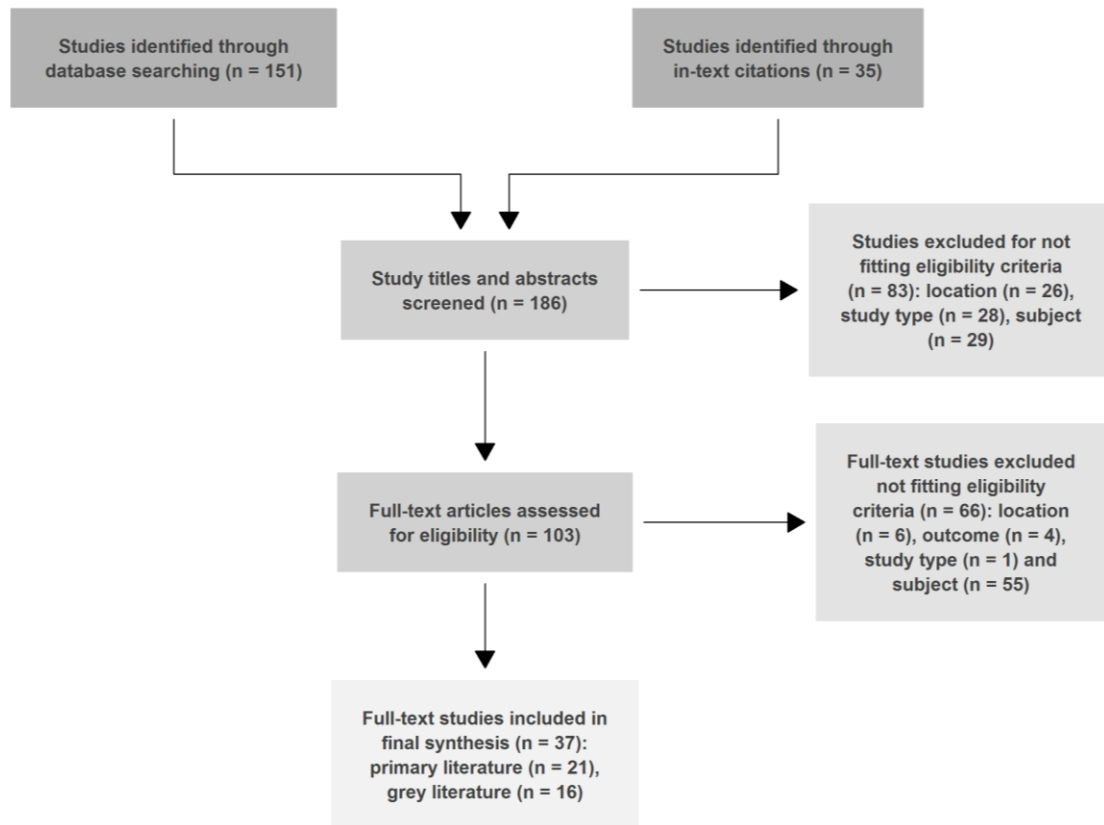
- 183 • Publication type: "Primary research" were those papers published in peer-reviewed
184 journals and reported original data or results from experiments, observations or
185 models. "Grey literature" included technical reports, book chapters and unpublished
186 reports.

- 187 • Spatial scale of each study: ‘local’ (relating to a restricted number of study sites
188 within a country), ‘national’ (addressing issues at a national scale), ‘regional’
189 (examining patterns across the Caribbean).
- 190 • Type of analysis: predominately qualitative or quantitative.
- 191 • Study perspective: predominantly biophysical processes, economic, or socio-cultural.
- 192 • Ecosystem service category and subcategory (according to the MEA framework) (see
193 Table S1 for definitions).
- 194 • Classification of ecosystem service component: ‘supply’ (potential to generate a
195 service), ‘delivery’ (the amount/rate of use and access to service), ‘wellbeing’
196 (change in human wellbeing due to provision of service) and ‘value’ (monetary or
197 non-monetary value of service), following the framework of Balvanera et al. (2017).

198 One reviewer conducted the search of electronic databases, recording the number of
199 citations for each search. Articles were initially viewed by one reviewer, assigning them to
200 all questions they addressed or, excluding them from further analysis if they did not meet
201 the inclusion criteria, on review of the abstract or summary. Two reviewers examined a 20%
202 proportion of studies to check corroborate study inclusion. Descriptive statistics were used
203 to determine the number of studies for each category for the variables identified in the
204 search protocol. Temporal change in research output was determined using linear
205 regression for the publication date of all studies. All analyses were conducted in the R
206 software environment (R Core Team, 2016).

207 **3. Results**

208 Of the results identified from all searches (n=186, removing all repetitions across
209 databases), 37 qualified as addressing the three study aims (see Table 1 for examples of the
210 included studies and supplementary material for a full list of these studies), with a lack of
211 subject relevance the most common reason for rejection (53.40%) (Fig. 1). There was no
212 temporal increase over time in the number of studies published ($p = 0.06$, Fig. S2).



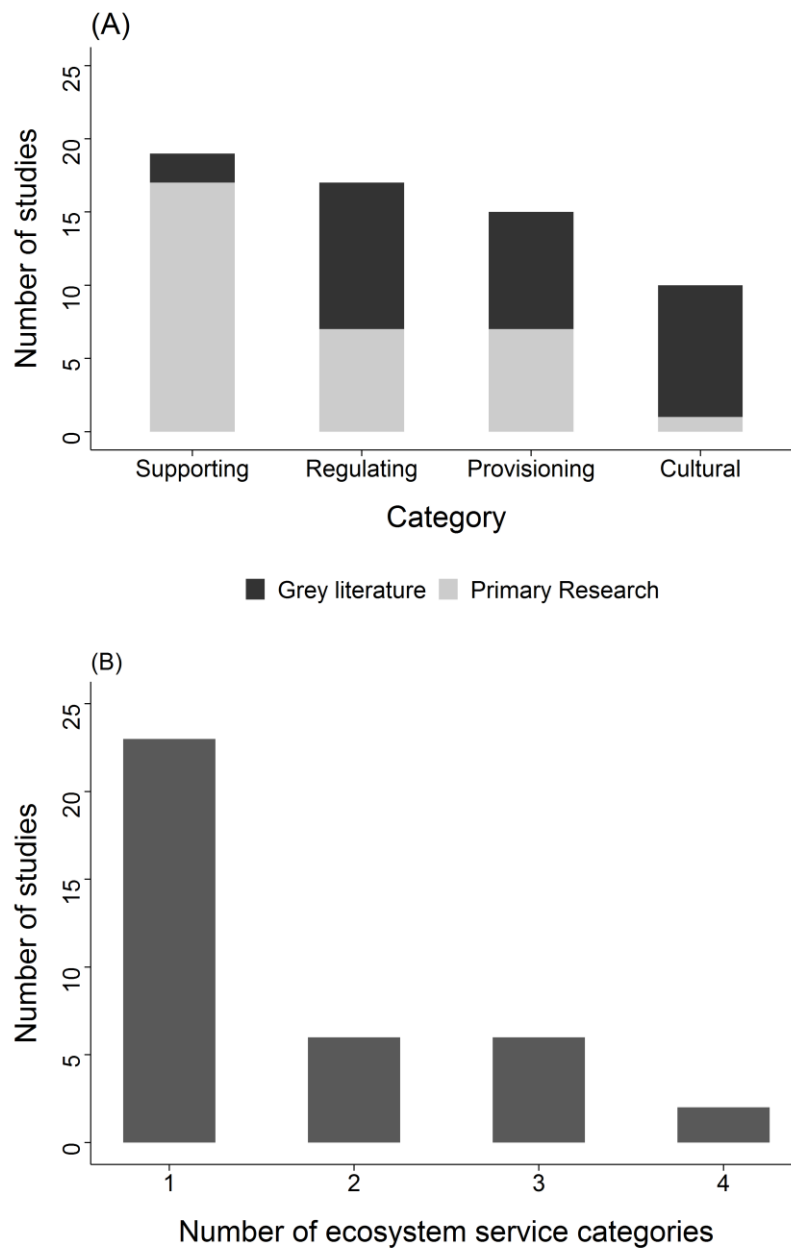
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214 Figure 1. Flow diagram describing the results of the systematic review search strategy.

215

216 The majority of studies came from primary literature (56.76%), although the proportion
 217 varied across ecosystem service categories, with cultural services having the highest number
 218 of grey literature (Fig. 2A). All included studies were predominantly quantitative in their
 219 analysis type, and no qualitative studies were identified in the review. Supporting services
 220 studies comprised the majority of results (31.14%, Fig. 2A), with most studies addressing
 221 just one category and only two studies reporting on all ecosystem service categories (Fig.
 222 2B). Most studies were local (40.54%) or national (45.95%) in focus. Local- or nationally-
 223 focused studies originated from nine countries or dependent territories (Fig. 3A), with
 224 Puerto Rico having the total largest number of these studies (34.38%, n=11, see Table 1 for
 225 examples). When examining this pattern by category, Puerto Rico remained dominant for
 226 supporting services (Fig. 3A), but Bonaire was a focus for cultural services (Fig. 3A, see Table
 227 1 for examples). The average number of ecosystem service subcategories across all studies

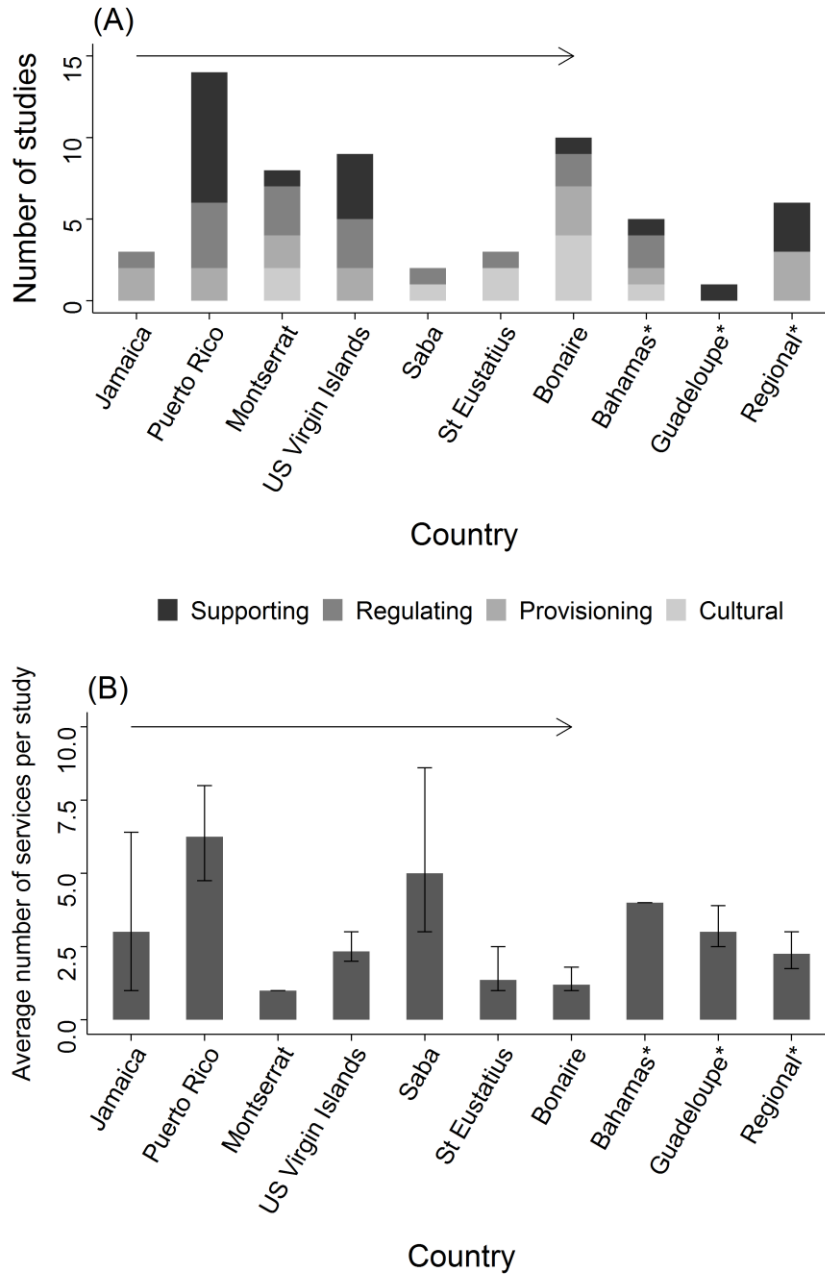
228 was 2.67 (95%CI 1.59- 5.69), with Montserrat and Bonaire addressing the highest number of
229 subcategories (Fig. 3B).



230

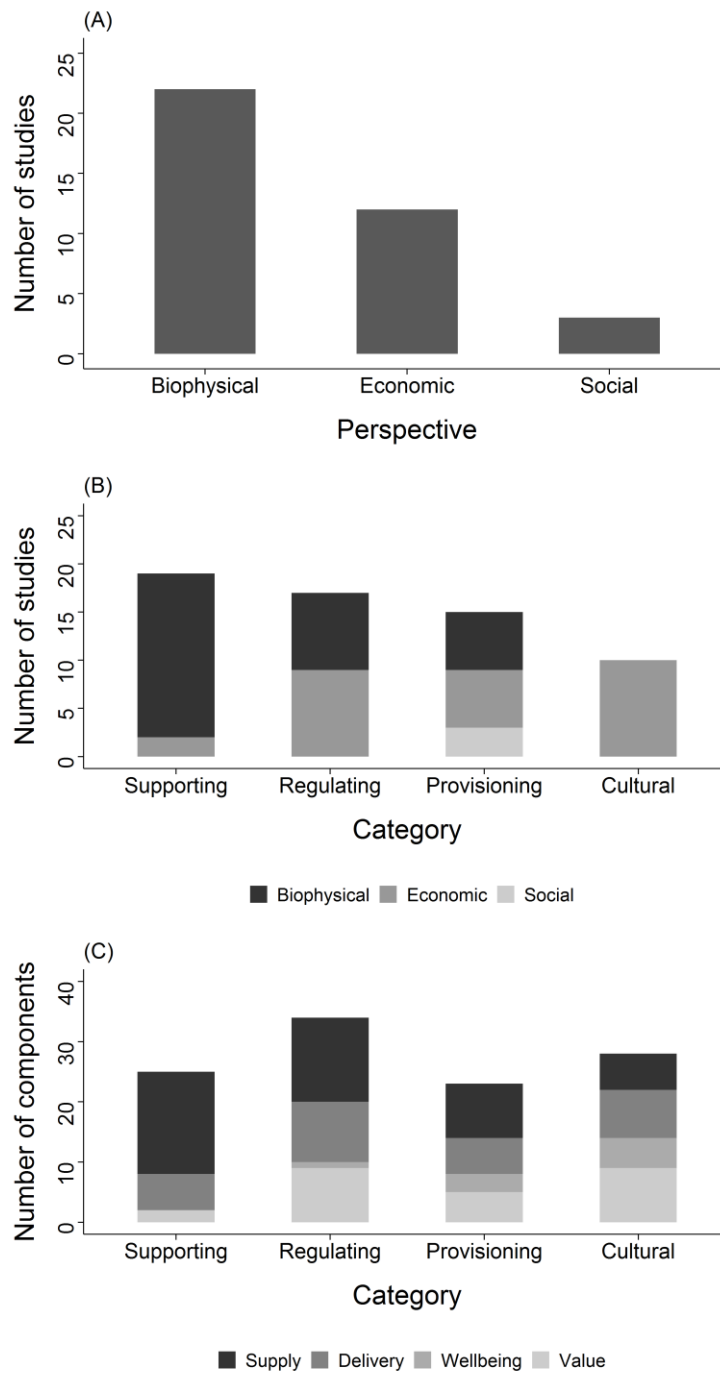
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232 Figure 2. Results of the systematic review for (A) each ecosystem service category by
233 publication type and (B) the number of ecosystem service categories described in each
234 study.



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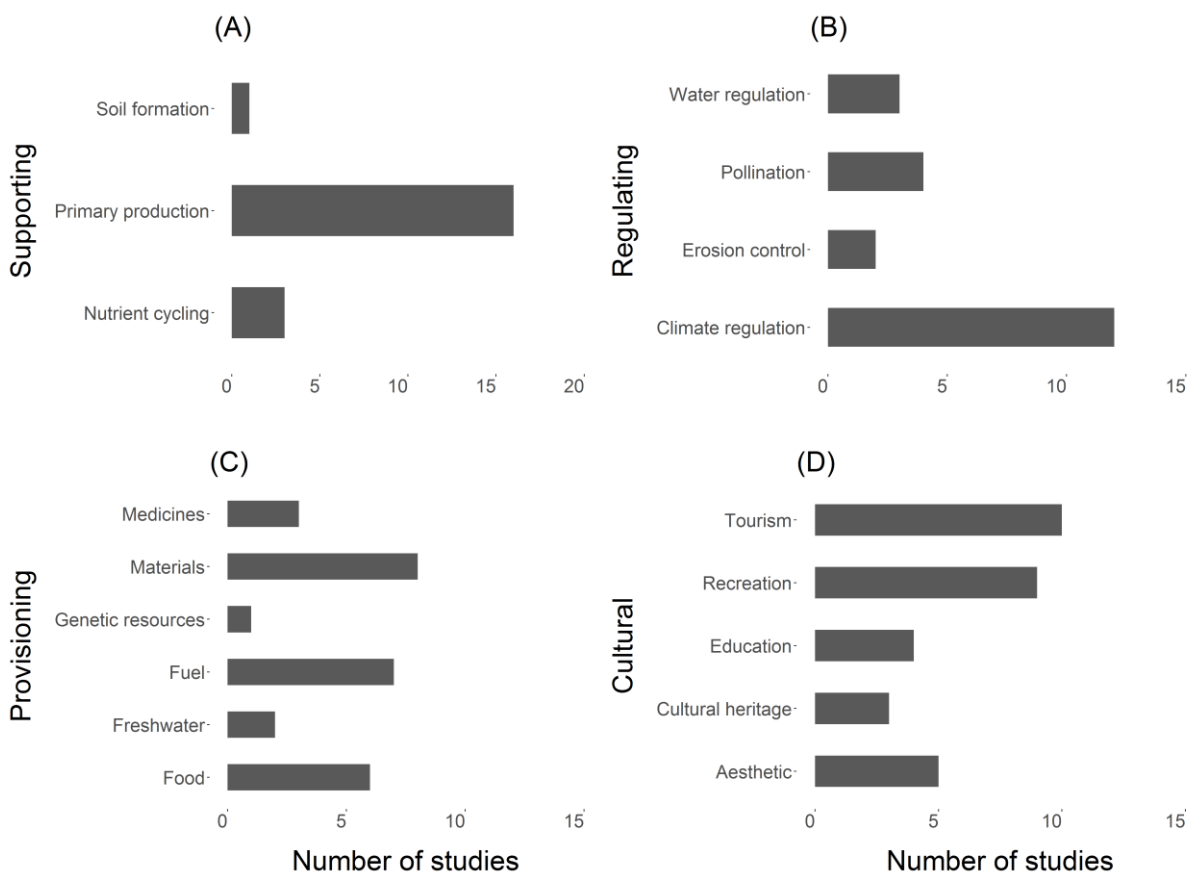
236 Figure 3. Per-country studies of TDF ecosystem services identified from the systematic
 237 review, showing (A) the number of studies per ecosystem service category and (B) the
 238 average number of ecosystem service components per study (within and across the four
 239 categories). Error bars indicate 95% confidence intervals and horizontal arrows indicate
 240 increasing proportion of TDF cover per country (see Table S2 for details); *no estimate of
 241 TDF cover.



245 Figure 4. Results of the systematic review showing (A) the study perspective taken across all
 246 publications (B) the study perspective for each ecosystem service category and (C) the
 247 classification of ecosystem service component by ecosystem service category.

249 Most studies were predominately biophysical in nature (59.46%), with socio-cultural
 250 perspectives being the least often presented in the literature (Fig. 4A, B). Supporting and
 251 regulating studies had the highest proportion and number of biophysical assessments (Fig.
 252 4B), while the proportion of studies with an economic perspective was highest in the
 253 cultural services category (Fig. 4B). In all categories except for cultural services, the supply
 254 classification measurement was predominant, being highest for the supporting services (Fig.
 255 4C). Wellbeing components were the least quantified component across all ecosystem
 256 service categories (Fig 4C). Primary production (predominately composed of biomass
 257 estimates) and climate regulation subcategories were the most studied supporting and
 258 regulating services, respectively (Fig. 5A, B, Table 1). Materials and fuel were most the most
 259 commonly studied provisioning service (Fig. 5A), while cultural studies had a predominately
 260 tourism and recreation focus (Fig. 5C, D, Table 1).

261



262

263 Figure 5. The major subcategories of ecosystem service categories covered in the literature
264 review; (A) supporting services, (B) regulating services, (C) provisioning services and (D)
265 cultural services.

266 Table 1. Examples of ecosystem services of Caribbean TDF based on the results of the systematic review. See Table S2 for details about the
 267 sovereignty and TDF coverage of the islands.

268

Service	Examples from Caribbean TDF	Island	Reference
Supporting			
Soil formation	Soil bulk density 0.4 g/cm ³ mature TDF	Puerto Rico	(Colón and Lugo, 2006)
Nutrient cycling	Dead wood a temporary sink for atmospheric carbon, source of soil organic matter, substrate for nitrogen fixation	Puerto Rico	(Torres and González, 2005)
Primary production	5.3-9.8 Mg ha ⁻¹ per year of primary productivity in Guanica TDF	Puerto Rico	(Clark et al., 2001)
	41.74 Mg ha ⁻¹ woody biomass in TDF (> 2.5cm DBH)	Puerto Rico	(Brandeis et al., 2007)
	29 Mg ha ⁻¹ woody biomass in TDF (> 2.5cm DBH)	Mona Island, Puerto Rico	(Brandeis et al., 2007)
	47.65 Mg ha ⁻¹ woody biomass in TDF (> 2.5cm DBH)	US Virgin Islands	(Brandeis and Oswald, 2007)
Regulating			
Climate regulation and related services	737,000 tons carbon stored in TDF	US Virgin Islands	(Brandeis and Turner, 2009)
	49.66 (Mt C) carbon stored in forest (approx. 17% TDF) (US\$925.41 million).	Puerto Rico	(Smith, 2007)
	Dead wood and litter comprised average of 20% of total carbon stocks in moist and dry life zones	U.S. Virgin Islands	(Oswald et al., 2008)
	621,000 tons yr ⁻¹ carbon (EC\$38,454 annually) in Centre Hills (9% land cover is TDF)	Montserrat	(van Beukering et al., 2014)

Service	Examples from Caribbean TDF	Island	Reference
	Value of carbon sequestration of main ecosystems (including TDF) estimated at \$290,000 annually; 115,927 tons yr ⁻¹ carbon stored in TDF; contribution of TDF >80% of all ecosystems;	Bonaire	(van Beukering and Wolfs, 2012)
	Cockpit County (approx. 10% TDF) carbon sequestration US\$10,425,092 annually	Jamaica	(Edwards, 2011)
	27,000 tons yr ⁻¹ carbon stored in TDF (US \$376,740 annually)	Saba	(Tieskens et al., 2014b)
	19,000 tons yr ⁻¹ of carbon stored in TDF (US \$261,979 annually)	St Eustatius	(Tieskens et al., 2014b)
	Percent concentration of carbon 45.7 ± 1.2, nitrogen 2.3 ± 0.3 and carbon: nitrogen ratio 20.7 ± 2.5 in <i>Cecropia scheberiana</i>	Puerto Rico	(González and Seastedt, 2001)
	High percentage of carbon (52.4 ± 4.5) and low nitrogen (1.4 ± 0.5) in 53 TDF species; high carbon: nitrogen ratio 48 ± 18 may be explained by N limitation and high % carbon.	Mona Island, Puerto Rico	(Medina et al., 2014)
Water regulation and related services	Estimate of changes in spring water yield as a result of deforestation: 75% loss under complete deforestation scenario	Montserrat	(van Beukering et al., 2014)
Pollination	Total value of pollination and seed dispersal in TDF estimated at US\$17,000,000.	Bonaire	(Cortes, 2012)
Provisioning			
Fuel	48% of TDF use in the Hellshire Hills and 51% in Portland Ridge related to charcoal and fuelwood use	Jamaica	(C-CAMF, 2013a, b)
	5% population collect charcoal/firewood from Centre Hills (including TDF)	Montserrat	(van Beukering et al., 2014)
Food	15% population collect fruit once or more annually from Centre Hills (including 9% TDF).	Montserrat	(van Beukering et al., 2014)

Service	Examples from Caribbean TDF	Island	Reference
	Total annual profit from hunting wild meat in the Centre Hills (9% TDF) US\$205,000	Montserrat	(Peh et al., 2015)
Materials	Red (<i>Cedrela</i> sp.) and white cedar (<i>Tabebuia</i> sp.) for furniture production (< 2% population) from Centre Hills (9% land cover is TDF), \$EC14.95 and \$EC15.00 per linear foot, respectively.	Montserrat	(van Beukering et al., 2014)
	2% population collect craft materials, e.g. seeds, beads, wood, bark, leaves, flowers (including TDF)	Montserrat	(van Beukering et al., 2014)
Freshwater	100 million gallons per month from Centre Hills (9% TDF), 80% for public supply; 88 million gallons sold annually (EC\$2,656,000).	Montserrat	(van Beukering et al., 2014)
Genetic resources	Low gene flow and genetic diversity in bat-pollinated <i>Hymenaea courbaril</i> ; high gene flow and diversity in fragmented <i>Bursera simaruba</i> populations and the insect-pollinated non-native <i>Albizia lebbek</i> .	Puerto Rico	(Dunphy, 2003)
Natural medicines	Large proportion of population regularly collect and use medicinal plants (from all ecosystems including TDF, worth \$344,394 annually)	Bonaire	(van Beukering and Wolfs, 2012)
	7% population collect medicinal plants (including TDF)	Montserrat	(van Beukering et al., 2014)
Cultural			
Recreation	Hunting (8%), Hiking, camping, wildlife watching, picnicking in Centre Hills (including 9% TDF)	Montserrat	(van Beukering et al., 2014; Peh et al., 2015)
	Recreational and cultural value of forested (TDF) habitat (US\$30,825 annually)	Saba	(Tieskens et al., 2014a)
	Hiking, natural landscapes, including TDF	St Eustatius	(Tieskens et al., 2014b)
	Wildlife viewing, natural environment, including TDF (EC\$20-25 million annually).	Montserrat	(van Beukering et al., 2014)

Service	Examples from Caribbean TDF	Island	Reference
Tourism	Hiking in forested (TDF) habitat (US\$3,233,386 annually)	Saba	(Tieskens et al., 2014a)
	Total value of terrestrial tourism for island, US\$1,231,309.84 annually	St Eustatius	(Tieskens et al., 2014b)
	TEEB models suggest US\$15000 could be generated annually from birdwatching, including in TDF	Bonaire	(Cortes, 2012)
Aesthetic, spiritual, inspirational	Total annual expenditure US\$419,000 from International tourists to Centre Hills (including 9% TDF)	Montserrat	(van Beukering et al., 2014; Peh et al., 2015)
	Value of artistic inspiration of all ecosystems (including TDF) estimated at \$460,000 annually	Bonaire	(van Beukering and Wolfs, 2012)
	Local residents were willing to pay US\$9.07 per month for high quality terrestrial habitat (including TDF)	Bonaire	(Lacle et al., 2012)
Cultural heritage	Local value for culture and recreation US\$41,315 (including TDF)	St Eustatius	(Tieskens et al., 2014b)
Educational	Education impact of natural resources on Andros Island, Bahamas, estimated at US \$2,800 (209)	Bahamas	(Hargreaves-Allen, 2010)
	Total value (including TDF) for scientific research estimated US\$1,240,000 - US\$1,485,000	Bonaire	(van Beukering and Wolfs, 2012)

270 4. Discussion

271 Caribbean TDFs are recognised as being significantly under-researched compared to TDFs
272 across Latin America (Blackie et al., 2014). Our results are consistent with this observation,
273 identifying substantial knowledge and geographic gaps in the evidence for ecosystem
274 services in Caribbean TDFs. Here, we discuss the findings from this systematic review,
275 highlighting the status of our current understanding and important knowledge gaps,
276 relevant to mainstreaming ecosystem services in the Caribbean (Bizikova et al., 2018), and
277 discuss the potential research opportunities that can improve the relevance of these data to
278 ecosystem services policy in the region.

279 4.1. *Patterns in research effort*

280 In contrast to much of the wider ecosystem service literature (Liquete et al., 2013; Luederitz
281 et al., 2015; Cruz-Garcia et al., 2017; Balzan et al., 2018), there was no significant temporal
282 increase in research of Caribbean TDF ecosystem services. Although this pattern was in part
283 due to the small sample size of eligible results, it may also reflect the generally low global
284 research effort for TDF systems compared to other forest systems. Nearly half of the search
285 results were published in the grey literature, highlighting the importance of including such
286 information in knowledge assessments. Such publications are vital for bridging the
287 researcher-practitioner gap, since peer-reviewed literature is often unobtainable by
288 practitioners or often asks the wrong questions (Gossa et al., 2015). Yet, many reviews of
289 ecosystem services omit these valuable data (e.g. Liquete et al., 2013; Luederitz et al., 2015;
290 Malinga et al., 2015; Calvo-Rodriguez et al., 2017). As is also established for Caribbean
291 marine ecosystem services (Schuhmann and Mahon, 2015), our results demonstrate that
292 their inclusion is justified to avoid a mis-representation of the current state of knowledge.

293 The larger islands (Cuba, Hispaniola, Puerto Rico and Jamaica) have the greatest extent of
294 TDFs (Portillo-Quintero and Sánchez-Azofeifa, 2010), but not necessarily the greatest
295 relative proportion of TDF forest cover (Table S1). The published English-language literature
296 on ecosystem services in these Greater Antillean TDFs reflects, in part, this distribution. Yet,
297 in general, there was low research effort in those islands with proportionally high TDF forest
298 cover, with Puerto Rico having disproportionately high research effort compared to

299 coverage of TDF, indicating that the amount of TDF per se, is not a driver of research.
300 Unsurprisingly, many of the countries represented in this review are overseas departments
301 or dependencies (e.g. Puerto Rico, Caribbean Netherlands) with external support (such as
302 the International Institute for Tropical Forestry of the US Forest Service), host large
303 universities (e.g. Universidad de Puerto Rico, University of the West Indies-Mona Jamaica),
304 and/or large remaining tracts of TDFs (e.g. Jamaica). Extending the language scope of this
305 review would provide further insight into these patterns, since restricting this review to
306 English-speaking publications undoubtedly led to an underrepresentation of research effort,
307 although it should be noted that four of the islands represented in the review are non-
308 English speaking (Bonaire, Guadeloupe, Saba, St Eustatius).

309 In this review, as found elsewhere (Cruz-Garcia et al., 2017), studies tended to focus on two
310 or less ecosystem service categories. This narrow focus is repeated when examining the
311 number of ecosystem components per study, which is also observed more widely in the
312 study of ecosystem services (Seppelt et al., 2011; Liqueste et al., 2013; Weitzman, 2019).
313 Examining ecosystem services in isolation runs the risk of failing to understand processes
314 such as cascading effects, feedbacks, trade-offs and interactions between services. This is
315 particularly true for ecosystem services on islands, given their unique ecological
316 characteristics and socio-economic challenges (Balzan et al., 2018). The importance of
317 understanding this aspect of ecosystem services is increasingly recognised for achieving
318 effective translation into decision-making, such as in the context of biodiversity loss and
319 climate change (Seppelt et al., 2011; Evers et al., 2018). Such mainstreaming of ecosystem
320 service data into policy-relevant information, requires an explicit consideration of the need
321 for integration of policy-makers in the process of study objective formulation and data
322 generation (Rosenthal et al., 2015; Bizikova et al., 2018).

323 Studies of supporting, regulating and provisioning ecosystem services often have a
324 biophysical focus (Martínez-Harms and Balvanera, 2012; Liqueste et al., 2013; Evers et al.,
325 2018), reflecting that these measures are typically components of ecologically rather than
326 economically focused studies (Czúcz et al., 2018). This pattern was also observed for
327 Caribbean TDF. The high proportion of studies focusing on supporting, regulating and
328 provisioning services is consistent with other studies (Martínez-Harms and Balvanera, 2012;

329 Luederitz et al., 2015; Malinga et al., 2015; Calvo-Rodriguez et al., 2017). Here, estimates of
330 biomass, a fundamental measurement of forest inventories (e.g. Brandeis and Turner, 2009)
331 were dominant. These data in particular, demonstrate the value of long-term monitoring
332 programmes such as those conducted by the International Institute for Tropical Forestry in
333 Puerto Rico. Such biophysical data are however, important foundations for translating
334 ecosystem functioning into measures of ecosystem services (Seppelt et al., 2011), thus
335 providing the basis for economic accounting.

336 Quantitative estimates of all ecosystem service categories were dominant in this review.
337 Although as is found more widely (Liquete et al., 2013; Luederitz et al., 2015; Malinga et al.,
338 2015), the absolute number of assessments of cultural ecosystem services was low, this
339 category had the highest proportion of studies taking an economic perspective. Such
340 market-based cultural values are comparatively easy to measure, using the commonly
341 applied contingent valuation and cost-based approaches (De Groot et al., 2002; Brooks et
342 al., 2014). This patterns is also observed for Caribbean marine systems (Schuhmann and
343 Mahon, 2015). However, the intangibility of many non-use cultural services, such as
344 aesthetics, means that they can be a challenge to quantify economically and to date, many
345 cultural valuations have focused on tourism and recreation services (Seppelt et al., 2011;
346 Liquete et al., 2013; Schuhmann and Mahon, 2015). This review echoes these findings.

347 To date, most ecosystem service research focuses on quantifying the supply element of
348 classifying ecosystem service components, since this is often the most easily quantified
349 (Tallis et al., 2012; Balvanera et al., 2017). Our results illustrate a similar pattern, with the
350 quantification of supply and delivery of ecosystem service provision comprising the majority
351 of all categories, consistent with the mainly biophysical focus of studies. As expected,
352 wellbeing was rarely quantified in our review, given the difficulties in understanding and
353 demonstrating change to human wellbeing (Balvanera et al., 2017; Cruz-Garcia et al., 2017).
354 Ecosystem services of TDF more widely have not yet been fully explored in the context of
355 this conceptual framework of supply, delivery and benefit (Tallis et al., 2012; Balvanera et
356 al., 2017). Applying such a framework in this review is a useful starting point for evaluating
357 the breadth and quality of existing data Caribbean TDF ecosystem services, leading to
358 improved understanding of these systems.

359 *4.2. Current understanding of Caribbean TDFs ecosystem services*

360 In the Caribbean, where water demand often exceeds availability (ECLAC, 2011), water
361 regulating services are arguably among the most important ecosystem service provided by
362 TDFs (Portillo-Quintero et al., 2015). For example, the Centre Hills Reserve in Montserrat, of
363 which TDF comprises 9%, produces 100 million gallons of water annually (van Beukering et
364 al., 2014), although the study does not distinguish between forest types. Given the
365 importance of water to TDF structure and functioning (Murphy and Lugo, 1995), as well as
366 to humans, the low frequency of water-related services publications in the literature is of
367 concern, especially since water processes in TDF are highly sensitive to temporal and spatial
368 water availability (Balvanera et al., 2011). This poor understanding of water ecosystem
369 services was also observed for TDF more widely (Calvo-Rodriguez et al., 2017; Quijas et al.,
370 2019) and is consistent with a broader lack of understanding of the hydrology in these
371 systems (Farrick and Branfireun, 2013).

372 As illustrated in this review, carbon-related supporting, regulating and provision services are
373 the most widely estimated ecosystem services for Caribbean TDFs. These studies
374 demonstrate the substantial carbon storage function of TDFs, most commonly measured
375 through woody biomass. Measuring biomass is recommended for decreasing uncertainty in
376 our understanding of climate cycles and improving estimates of terrestrial carbon stocks and
377 carbon accounting and, is also an important indicator of other ecosystem services
378 (Houghton et al., 2009; Le Toan et al., 2011). Although woody biomass is generally lower in
379 TDFs than moist forest (Brandeis and Turner, 2009), in many of the drier islands, TDF is the
380 dominant forest type. Based on this review, increasing the existing low coverage of TDF in
381 protected areas in the Caribbean (Oatham and Boodram, 2006b) could make a substantial
382 contribution to ecosystem service provision for these islands. In this context, efforts should
383 be made to translate the mostly biophysical estimates of woody biomass into the economic
384 value of this service.

385 TDFs provide multiple provisioning services in the Caribbean, including energy, food, and
386 materials, such as non-timber forest products (NTFPs). For example, charcoal from TDF
387 remains an important source of fuel in many islands, including Jamaica and Montserrat (C-

388 CAMF, 2013b; van Beukering et al., 2014). Although production forestry has declined in the
389 Caribbean (John, 2005), NTFP use including medicines and crafts from TDF is widespread
390 (e.g. FAO, 2010; van Beukering et al., 2014), as highlighted in this review. However, across
391 the Neotropics the provisioning services of TDFs are negatively impacted by habitat
392 alteration (Balvanera et al., 2011; Portillo-Quintero et al., 2015), such as due to extreme
393 weather or anthropogenic impacts. While data on habitat degradation or reduction are not
394 widely or reliably available for the insular Caribbean, the findings from this review suggest
395 that a reduction in ecosystem functioning of Caribbean TDF could have a tangible economic
396 impact for local communities in the region.

397 Recreation, tourism and aesthetics are consistently demonstrated as valuable cultural uses
398 of Caribbean TDF ecosystems in this review. Local communities value intact TDF habitat,
399 with residents of Bonaire willing to pay nearly US\$10 per month for terrestrial habitat to
400 remain in good condition (Lacle et al., 2012). The reliance of many countries on tourism also
401 means that TDF habitat can be worth up to US\$3 million annually on individual islands for
402 hiking and birdwatching (Cortes, 2012; Tieskens et al., 2014a; Tieskens et al., 2014b).
403 However, existing knowledge is patchy across the region, with cultural assessments having
404 the smallest number and geographic range of studies in this review. Ironically, in many
405 islands TDF habitat is viewed as low value scrub and is often converted to agriculture (Wilkie
406 et al., 2002; Peters, 2011), despite the potential value for tourism. This possible disparity in
407 perception between culturally important and valueless TDF demands further examination
408 for the Caribbean.

409 *4.3. Gaps in knowledge and identifying constraints*

410 We found substantial knowledge gaps of ecosystem services for Caribbean TDF. For
411 example, our study found limited quantification of water provisioning by TDFs in the
412 Caribbean, while genetic studies were almost non-existent and as found for other
413 Neotropical TDFs (Calvo-Rodriguez et al., 2017; Quijas et al., 2019), there were no studies on
414 air-related services. With many Caribbean TDF now considered novel communities due to
415 IAS species in these systems (Lugo et al., 2006), a further absence from this review was the
416 quantification of the relative contribution of native and introduced species to ecosystem

417 service provision and, the relative resiliency of native communities to resist invasive species
418 colonisation and establishment. These gaps indicate a considerable limitation in our
419 understanding of the response of TDF ecosystem services to environmental change, such as
420 climate change (see Nelson et al., 2018), as well as our ability to assess the total economic
421 value of these systems. Much of the focus for ecosystems services of Caribbean SIDS has
422 been on coastal, coral reef and mangrove ecosystems (e.g. see Schuhmann and Mahon,
423 2015 and references therein). However, research on TDF ecosystem services the insular
424 Caribbean have been limited, unlike the rest of Latin America (e.g. Maass and Burgos, 2011;
425 Calvo-Rodriguez et al., 2017) where work on these forests is rapidly advancing.

426 In the Caribbean, there are a lack of cultural valuations for TDFs, although these are notable
427 for the Dutch dependencies (van Beukering and Wolfs, 2012; Tieskens et al., 2014b). This
428 gap is particularly apparent in the primary literature and the failure to understand the
429 relationship of local communities with TDF is a recognised limitation for management in the
430 Neotropics (Sánchez-Azofeifa et al., 2005a; Blackie et al., 2014; Castillo et al., 2018).
431 Importantly, few studies in this review quantified the human wellbeing benefits of TDF,
432 possibly since these indicators are considered hard to measure (Balvanera et al., 2017).
433 Participatory methods, sustainable livelihoods frameworks and policy network analysis are
434 vital to engage stakeholders and utilise local knowledge in order to advance socio-cultural
435 understanding (CANARI, 2016).

436 This review of ecosystem services provided by TDFs in the insular Caribbean, although
437 pointing to the importance of such TDFs services, suggests that generally, the published
438 evidence is limited in distribution and often un-replicated. In addition to the data gaps
439 described above, shortcomings identified by this review include the paucity of the
440 continuous long-term data on baseline ecosystem services, that is necessary to understand
441 inter-and intra-annual environmental variability (Lindenmayer et al., 2012). A further
442 consideration is that much of the existing literature does not clearly distinguish TDF from
443 other forest types. This may in part reflect that forest definitions are often dictated by
444 different management objectives, leading to a dichotomy between land management
445 versus production forestry (Chazdon et al., 2016). These knowledge weaknesses hinder our

446 ability to determine long-term change in TDF ecosystem services, as well as our ability to
447 successfully influence decision-making.

448 Understanding gaps in knowledge requires an understanding of the underlying factors
449 influencing research in the insular Caribbean. A major constraint of ecological research in
450 SIDS such as the Caribbean, is lack of resources and human capacity (Kaiser-Bunbury et al.,
451 2015). Widespread understaffing and high demands on natural resources managers limits
452 the indigenous ability to undertake the long-term research that is required to answer vital
453 questions about TDF systems. Increasing the capacity of natural resource managers, through
454 training, motivation and technical support, is instrumental for future long-term forest
455 management and research (Marcano-Vega et al., 2016). While it is crucial to advocate for
456 capacity building, the long time-lags in developing professional level competence will lead to
457 the lack of capacity in Caribbean management agencies remaining a persistent challenge to
458 furthering research on TDF ecosystem services. Until increases in local capacity are realised,
459 collaborations with foreign researchers will remain important for understanding forest
460 systems. Yet, these researchers frequently fail to train, engage or share data with local
461 resource managers and researchers and unless this work is subsequently published, it rarely
462 gets into the realm of decision-makers (Kaiser-Bunbury et al., 2015). Permanent plots are
463 often set up by foreign researchers or by international collaborations, such as by the FAO
464 Tropical Forestry Action Programme in the 1980s, but then are infrequently re-visited or
465 data is not used for management due to lack of manpower, resources and loss of
466 institutional memory (Fairhead and Leach, 2002; Marcano-Vega et al., 2016). These
467 problems exemplify the challenge of bridging conservation science and application in SIDS
468 and emphasise the need for researchers to engage local practitioners (Kaiser-Bunbury et al.,
469 2015). Importantly, the relevance of ecosystem services research to environmental policy
470 hinges on the perceptions of the legitimacy of this research by policy makers (Posner et al.,
471 2016). Such legitimacy is central to the utility of ecosystem services research, to
472 mainstreaming of ecosystem services.

473 *4.4. The way forward*

474 Ultimately, a central goal of valuing ecosystem services is to facilitate mainstreaming into
475 national policies (Guerry et al., 2015). Evidence from valuation studies that have successfully
476 influenced decision-making in the Caribbean suggest that success stems from identification
477 of appropriate policy questions, fully engaging stakeholders, and transparency and strategic
478 communication (Waite et al., 2015). In the context of current ecosystem services research of
479 Caribbean TDF, this requires adopting an approach that is focused on data gaps and policy-
480 relevant questions that are co-constructed by stakeholders and researchers, rather than
481 more ad-hoc approaches based on data availability and methodological ease. In this context,
482 we make recommendations for key policy-relevant research (with examples of their policy
483 implications) (Table 2).

484

485 Table 2. Recommendations for future policy-relevant research, based on the systematic review of Caribbean TDF ecosystem services.

Recommendation	Knowledge gap for Caribbean TDF	Policy objective	Examples of research from Neotropical TDF	References
Total Economic Valuation (TEV) of ecosystem goods and services from TDF (e.g. UNEPs TEEB and Project for Ecosystem Services (ProEcoServ) UNEP).	Quantification of the economic and wellbeing value of services (Table 1, Fig.3, Fig. 4).	Provide economic incentive for mainstreaming ecosystem services into national planning accounting systems and develop framework for engagement of stakeholders in conservation of ecosystem goods and services from TDF.	The TEEB approach as used in the Dutch Islands, is a useful participatory framework to be more widely applied in the region.	(Cortes, 2012; Tieskens et al., 2014a)
Ground and surface water conservation value of TDF (e.g. using payment for ecosystem services, PES).	Contribution of TDF to water-related ecosystem services (Table 1, Fig. 5).	To quantify TDF contribution to water-related ecosystem services and so enable PES to sustainably finance TDF management and incentivise sustainable land management practices on private lands in watersheds, where climate-driven TDF expansion may be expected later in this century	PES models already successfully demonstrated for maintaining TDF in Chaco, Argentina. Long-term study of rainfall and water run-off in TDF, Mexico	(Maass et al., 2018; Nunez-Regueiro et al., 2018)
Co-benefits of TDF ecosystem function for agricultural production (e.g. pollination, soil conservation, water supply).	The value and importance of TDF ecosystem services to agricultural	Valuation of TDF contribution to the agricultural sector leads to rationalisation of incentivisation across the agriculture, forests and protected area sectors, promoting	Resiliency of TDF soil to pasture use in Mexico.	(Ayala-Orozco et al., 2018; Zelaya et al., 2018)

<p>Valuation of NTFPs (e.g. honey, medicinal plants, building materials, game wildlife and fruits) and pharmaceutical bioprospecting of TDF species (e.g. willingness-to-pay for potentially marketable forest-derived drugs).</p>	<p>productivity (Table 1, Fig. 5).</p> <p>Quantification of local community reliance on TDF NTFPS for livelihoods and subsistence (Table 1, Fig. 4, Fig. 5).</p>	<p>TDF conservation and long-term stakeholder education on sustainable land management practices on agricultural landscapes around TDF</p> <p>Monetise and diversify livelihoods, goods and services from TDFs to increase their perceived and actual value to local people and improve sustainability of NTFP management.</p>	<p>The impact of TDF fragments on pollination of Soybean, Argentina</p> <p>The economic value of TDF NTFPs for indigenous communities, Mexico</p> <p>The use value of TDF species for medicine and food, Mexico</p>	<p>(Marshall et al., 2006; Maldonado et al., 2013)</p>
<p>Long-term monitoring of climate change impacts on ecosystem functioning and provision of ecosystem services of TDF (e.g. changes in biomass, water regulation and pollination).</p>	<p>Lack of long-term data on TDF ecosystem service responses to environmental change (Table 1).</p>	<p>Develop climate change adaptation that explicitly addresses impacts on ecosystem goods and services in national policies and promote ecosystem management approach to manage transition to future drier climates.</p>	<p>Long-term study of TDF species drought tolerance, Caatinga, Brazil.</p> <p>Water availability, ENSO and primary productivity in Costa Rica</p>	<p>(Santos et al., 2014; Castro et al., 2018)</p>
<p>Impact of invasive alien species (IAS) on ecological functioning and ecosystem services of TDF (e.g. carbon storage, soil stability, aesthetic value).</p>	<p>IAS are identified as a major threat to TDF, but their impact on and contribution to ecosystem services remains unquantified (Table 1).</p>	<p>Implementation of monitoring and control to mitigate threats of existing IAS and avoid transportation of potentially new IAS.</p>	<p>Litter decomposition in novel TDF communities, Puerto Rico.</p>	<p>(Peh et al., 2015; Lugo and Erickson, 2017)</p>

			Economic impact of feral livestock control, Montserrat	
Genetic resources (provisioning of native and non-native TDF species (e.g. genetic diversity, resistance to disease, adaptive capacity)).	Contribution of genetic factors to TDF provisioning services and their response to environmental change (Table 1, Fig. 5).	Quantify threats to, and value of genetic diversity, ensure equitable sharing of benefits provided by TDF species.	Effects of fragmentation on genetic structure and reproductive success of TDF species, Costa Rica.	(Fuchs et al., 2003; Villalobos-Barrantes et al., 2015)
			Genetic diversity of TDF timber species, Costa Rica.	
Health and well-being contributions of TDF (e.g. clean air and water supply, flood protection, access to TDF, livelihoods).	Knowledge gap: the role of TDF in local health and wellbeing, culture and livelihood provision (Table 1, Fig. 2-5).	Mainstream ecosystem services and explicitly link human health, environmental and agricultural policies, that promote sustainable land management.	Impact of protected areas for local communities wellbeing and livelihoods, Brazil.	(Maass et al., 2005; Anaya and Espírito-Santo, 2018)
			Human wellbeing under future management scenarios	

487 **5. Conclusion**

488 This review highlights the relevance and contribution of TDFs for wider ecosystem and
489 socio-economic functioning in the insular Caribbean. Examining our current understanding
490 at a regional level provides a level of insight not possible from coarse-scale analyses. Here,
491 we highlight not only the strengths of current research but also key areas for future study.
492 Many of these gaps in knowledge reflect patterns and challenges experienced more widely
493 in SIDS. To move beyond biophysical assessments towards meaningful valuation and
494 successfully mainstreaming the ecosystem services of TDF into Caribbean decision-making
495 requires a collaborative and strategic assessment approach.

496

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503

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