Global footprint of mislabelled seafood on a small island nation

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ABSTRACT

Seafood mislabelling is a global issue that affects consumers, target species, and the ability to manage fisheries. Due to their high demand and value, groupers (Epinephelinae spp.) are frequent targets for fraudulent substitution on the world's major seafood markets. Yet, little is known on the prevalence of grouper mislabelling in the Wider Caribbean Region. We conducted the first 'grouper' authentication survey in the Turks and Caicos Islands (TCI), a luxury tourist destination where the locally caught but critically endangered Nassau grouper (*Epinephelus striatus*) features prominently on menus. DNA barcoding was used to assess mislabelling of market samples and simultaneously to gauge compliance with the Nassau grouper closed season. Our genetic analyses did not detect banned Nassau grouper, but only 18% of samples from restaurants and stores were confirmed as Epinephelinae (i.e. groupers), and 96% were mislabelled in some way. Substitutes for grouper mostly comprised freshwater catfish (*Pangasianodon hypophthalmus*; 57% of samples) and snappers (Lutjanidae; 25%), whereas samples sold as 'local grouper' were from Indo-Pacific or Asian inland waters. Only 22% of samples were matched to species found locally, all being cubera snapper (*Lutjanus cyanopterus*). Our study suggests that (i) mislabelling is motivated predominantly by financial incentives and/or driven by low supplies of groupers, (ii) local fishers are not the main source of mislabelled grouper into the supply chain, and (iii) the primary victims are consumers, fishing communities, and ultimately fragile fish stocks. Our findings can be used to help improve transparency, traceability and accountability in local seafood supply chains.

1. Introduction

Groupers (subfamily Epinephelinae, family Serranidae) are an assemblage of mostly reef-dwelling fishes comprising ca. 160 species in 16 genera (Craig et al., 2011; Fricke et al., 2020; Froese and Pauly, 2019). They are heavily exploited throughout their predominantly tropical and subtropical ranges, where they maintain a high market value, and are important components of industrial, small-scale, and artisanal fisheries (Heemstra and Randall, 1993; Sadovy de Mitcheson et al., 2013). Unfortunately, many groupers have life-history characteristics that make them vulnerable to fishing, including attaining large sizes, being long-lived, maturing late, and forming spawning aggregations (Coleman et al., 2000), and most species are components of complex multi-species reef fisheries that are difficult to manage (Roberts and Polunin, 1993; Amorim et al., 2018). As a consequence, grouper populations have declined (Sadovy de Mitcheson et al., 2013)

and 16% of species are currently classified as being at risk of extinction ('critically endangered', 'endangered', 'vulnerable' or 'near threatened') by the International Union for Conservation of Nature (IUCN, 2020), with many data deficient species also likely to be vulnerable or endangered (Luiz et al., 2016).

In the Wider Caribbean Region, Nassau grouper (*Epinephelus striatus*) was once one of the most important fisheries targets (Sadovy, 1999). However, the species is now commercially extinct in a number of countries from its former range (Sadovy and Eklund, 1999) and is considered 'critically endangered' by the IUCN (Sadovy et al., 2018). In response, all harvests of Nassau grouper have been banned in Bermuda and the USA (including Puerto Rico and the US Virgin Islands) and seasonal closures designed to prevent fishing of spawning aggregations have been implemented in the Bahamas, Belize, Cayman Islands, Dominican Republic, Mexico, and the Turks and Caicos Islands (TCI). In 2017, the species was added to Annex III of the 'Protocol Concerning
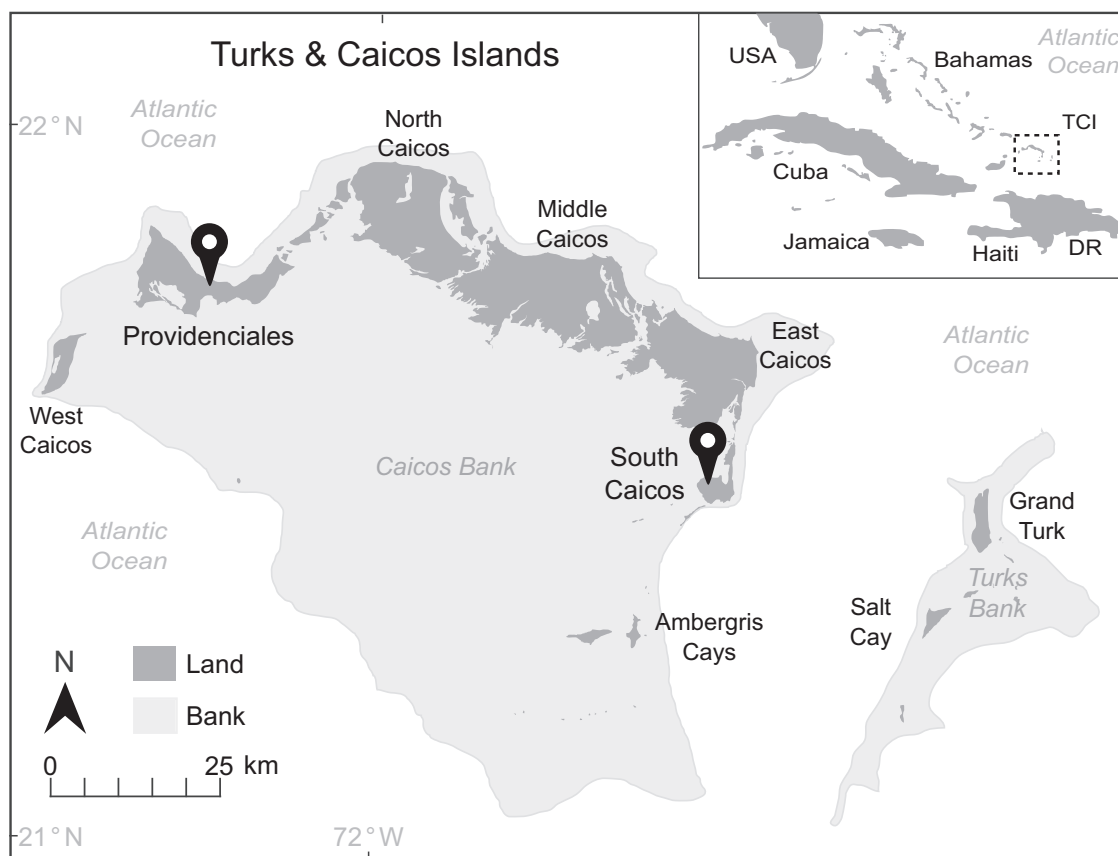
Fig. 1. The Turks and Caicos Islands, with the inset showing its position in the Wider Caribbean Region. Sample collection areas (Providenciales and South Caicos) are indicated with pins.

Specially Protected Areas and Wildlife (SPAW) in the Wider Caribbean Region' of the Cartagena Convention (UNEP, 2017). Although it remains questionable whether any sustainable fisheries of Nassau grouper persist (Cheung et al., 2013), the highest populations of Nassau grouper are believed to remain in the Bahamas, Belize, Cuba, and the TCI (REEF, 2019).

Seafood misrepresentation is a widespread problem with potentially serious economic, environmental and human health repercussions (Jacquet and Pauly, 2008). Incidents of mislabelling have been reported from over 50 countries (Warner et al., 2016), and a recent meta-analysis estimated the most credible global rate of mislabelling to fall between 4 and 14% (mode = 8%; Luque and Donlan, 2019). While some of this mislabelling may be accidental (e.g. due to species misidentifications, confused nomenclature and regulatory ambiguities), the deliberate and fraudulent mislabelling of seafood is commonplace and occurs at multiple nodes in the supply chain (Hu et al., 2018; Shehata et al., 2018). Reasons for intentionally falsifying the identity or provenance of seafood can include increasing profits, evading regulations and restrictions to trade, masking ethical concerns and health risks from consumers, and laundering of illegally sourced products into legitimate markets (Warner et al., 2016; Fox et al., 2018; Donlan and Luque, 2019). Due to their high value and strong demand, groupers are among the primary candidates for seafood fraud. Globally, the rate of grouper mislabelling is estimated at 30% (Luque and Donlan, 2019), with substitutes typically being lower-valued and often foreign farmed species (Table A1, Suppl. Info.). Although high levels of grouper mislabelling have been observed in Belize (ca. 69% of samples; Cox et al., 2013), the extent to which such mislabelling is occurring throughout the rest of the Wider Caribbean Region remains unquantified.

Here, we address this issue by conducting the first structured grouper authentication survey across the TCI, a small archipelago

nation and luxury tourist destination in the Wider Caribbean Region. As part of the TCI's cultural heritage, and being popular among foreign visitors, 'grouper' has long held a prominent place on local markets and menus. However, the foundations for mislabelling in the TCI appear to be strong: (1) mislabelling would be profitable because 'grouper' has one of the highest values of local seafood, with ex-vessel prices for whole fish reaching USD 15 kg^{-1}, main courses ranging from USD 18 to 42, and fillets in supermarkets often exceeding USD 100 kg^{-1}; (2) 'grouper' is the most popular local fish, but fishers focus on alternative species and are unable to meet the demand (Rudd, 2003, 2004; author's unpublished data), a problem exacerbated by the continued growth of resident and tourist populations (Turks and Caicos Statistics Department, 2019) and by tighter fishing regulations; (3) substitutes for grouper are available locally, such as domestically caught fish including lower-value reef fishes and unmarketable or illegal product (as observed in Belize; Cox et al., 2013); (4) vendors are unlikely to be held accountable for mislabelling as they have a high turnover of short-stay tourist customers, many of whom may not be able to tell when grouper is substituted (Ropicki et al., 2010); and (5) there is no government monitoring of seafood labelling.

In addition, public concern over the health risks from mislabelled fillets of undesirable species has been documented in the TCI (Schneider, 2012), and there are numerous anecdotal reports from both residents and visitors that alternative species are being sold as 'grouper', in particular imported farmed species and banned parrotfish. It is also suspected that Nassau grouper is disguised as other species of grouper during its closed season. Therefore, to explore these possibilities, we employed a forensically-validated DNA barcoding method (Dawnay et al., 2007) to elucidate the species diversity underpinning the local 'grouper' trade, with the core aims of: (i) evaluating the level of grouper mislabelling in the TCI, and (ii) investigating possible

circumvention of the Nassau grouper closed season by labelling *E. striatus* as other species.

2. Materials and methods

2.1. Study area

The study was conducted in the TCI, a British Overseas Territory in the Wider Caribbean Region (Fig. 1). The TCI is a small country with ca. 40,000 permanent residents, and an economy based on high-end tourism, offshore banking, and small-scale fisheries (Tietze et al., 2006; Turks and Caicos Statistics Department, 2019). Although approximately 250 full-time commercial fishers operate throughout the TCI (Calosso and Claydon, 2016), seafood is predominantly landed on the islands of South Caicos and Providenciales, the latter also being the centre of tourism in the country. Since the 1950s, TCI fisheries have focused on queen conch, *Lobatus gigas*, and spiny lobster, *Panulirus argus*, primarily caught by free-diving fishers and exported to the USA (Béné and Tewfik, 2001; Rudd, 2003). Historically, reef fishes were mostly speared opportunistically by lobster fishers (Medley and Ninnes, 1999; Rudd, 2003). More recently, the growing demand from tourism and rising TCI population has led to a fishery specifically targeting reef fishes for the domestic market (Rudd, 2003). Although up to 19 species of Epinephelinae are reported to be found in TCI waters (Table A2, Suppl. Info.), 'grouper' is the common name often used specifically for Nassau grouper, especially among fishers (author's unpublished data). However, the term is more ambiguous when used on menus, particularly those targeting tourists.

2.2. Sample collection

We collected samples from restaurants and stores across Providenciales and South Caicos during the Nassau grouper closed season (December 2017 – February 2018), as well as one during the open season for Nassau grouper (March 2018). We screened a total of 38 samples, including 34 from meals purchased in restaurants (all cooked) and confirmed as 'grouper' on the menus or verbally by vendors, and four from fillets labelled as 'grouper' in stores (all fresh). The stated common names of all samples were recorded. Although we attempted to balance the sample sizes from restaurants and stores, collections were inevitably based on availability in the given outlets, with ca. 50% of all visited restaurants and 80% of stores, markets, and roadside stalls that sell fish not having grouper for sale on the days of sampling. Consequently, samples were taken from 18 restaurants and 2 stores.

Following collection, tissue sub-samples (ca. 2 mm thick) were excised from each specimen, placed in 2-ml labelled microcentrifuge tubes containing silica beads (minimum 10:1 ratio of silica to fish tissue) and were kept frozen (-20 °C) until transferal to the UK laboratory. This sample preservation method was preferred over immersion in ethanol or other flammable liquids to avoid potential issues with transporting the samples by air.

2.3. DNA analysis

We extracted genomic DNA from each sample using a Chelex resin protocol (Estoup et al., 1996). A ca. 650 base-pair fragment of the mitochondrial cytochrome *c* oxidase I (COI) gene was subsequently amplified by polymerase chain reaction (PCR) using the fish-barcoding primer cocktail (C_FishF1t1/C_FishR1t1), reaction mixtures and thermal cycling regime from Ivanova et al. (2007). A detailed description of the molecular methods is provided in the Supplementary Information. PCR products were purified and sequenced by Macrogen Europe (Amsterdam, Netherlands). Quality edited sequences were thereafter identified in GenBank (www.ncbi.nlm.nih.gov), cross-referencing the results in the Barcode of Life Database (BOLD, www.

boldsystems.org) 'Species-Level' and 'Public Records' repositories. For each sample, we assigned species identifications based on top matches of ≥98% across the three queried sequence databases (Cawthorn et al., 2018). Nonetheless, possible candidate species with < 2% divergence were additionally recorded and were considered along with the top matches when evaluating grouper mislabelling (Table A3, Suppl. Info.). In cases where amplification failed or where sub-optimal reads were obtained with the full COI fish-barcoding primer cocktail, we repeated the PCR using mini-barcode primers targeting the COI gene (mI-COIintF/jgHCO2198) and 12S rRNA gene (MiFishUF/MiFishUR) as described in Leray et al. (2013) and Miya et al. (2015), respectively. Sequencing and sequence analysis with mini-barcode primers were conducted as previously described.

2.4. Likely origins

Samples were traced to their potential source fisheries using the method detailed by Cawthorn et al. (2018). Briefly, FishBase (Froese and Pauly, 2019) was used to determine the FAO major fishing areas in which each of the genetically identified species are natively distributed, with fractional scores being equally assigned to each recorded area as proportions of 1. Scores were then summed across FAO areas, and linkages between species and potential origins were visualised in Circos (Krzywinski et al., 2009).

2.5. Evaluation of labelling accuracy

For each analysed sample, we compared the declared common name and top species match (highest % similarity) obtained via DNA sequencing with the locally applicable common/market name and corresponding scientific name(s) listed in FishBase (used in the absence of an authoritative list of approved names in the TCI; Froese and Pauly, 2019). We considered samples to be correctly labelled when the species inferred from the stipulated common name agreed with the top genetic match or any other candidate species (≥98% similarity) (Table A3, Suppl. Info.). For samples additionally described as 'local', we considered these as correctly labelled if genetically identified as species natively distributed in the TCI or its Exclusive Economic Zone (EEZ). Lastly, by calculating posterior modes and Bayesian (Jeffreys) confidence intervals (BCIs) with the R package 'prevalence' v 0.4.0, we statistically analysed rates at which (i) different families were sold as 'grouper', (ii) samples were represented by species occurring locally, and (iii) samples were labelled correctly by species and origin. Posterior modes were used because they are better estimates of central tendency for rates of mislabelling than naïve means (Luque and Donlan, 2019).

3. Results

Identification results for the 'grouper' products collected across the TCI are summarised in Fig. 2 and provided in full in Table A3 (Suppl. Info.). Of the 38 samples screened, 28 delivered interpretable DNA sequences: i.e. 26 were identified to the species level based on their full COI barcodes and an additional two were identified based on mini barcodes (one to genus level, one to species level). Six samples failed to amplify and four did not return reliable matches in GenBank or BOLD (i.e. no match or < 98% similarity), with DNA degradation or PCR inhibition being the most likely explanations given the highly processed nature of the investigated samples (i.e. cooked, deep-fried, seasoned etc.).

In total, we genetically identified six species, representing four genera and three families (Fig. 2). Only five of the matched samples (mode = 18%) were assigned to the subfamily Epinephelinae, which comprised three Indo-Pacific species (*E. coioides* [n = 2], *E. malabaricus* [n = 1] and *E. tauvina* [n = 1]), as well as one sample identified as *Epinephelus* sp. whose origin could not be accurately determined. The bulk of samples (n = 16; mode = 57%) were found to be striped catfish
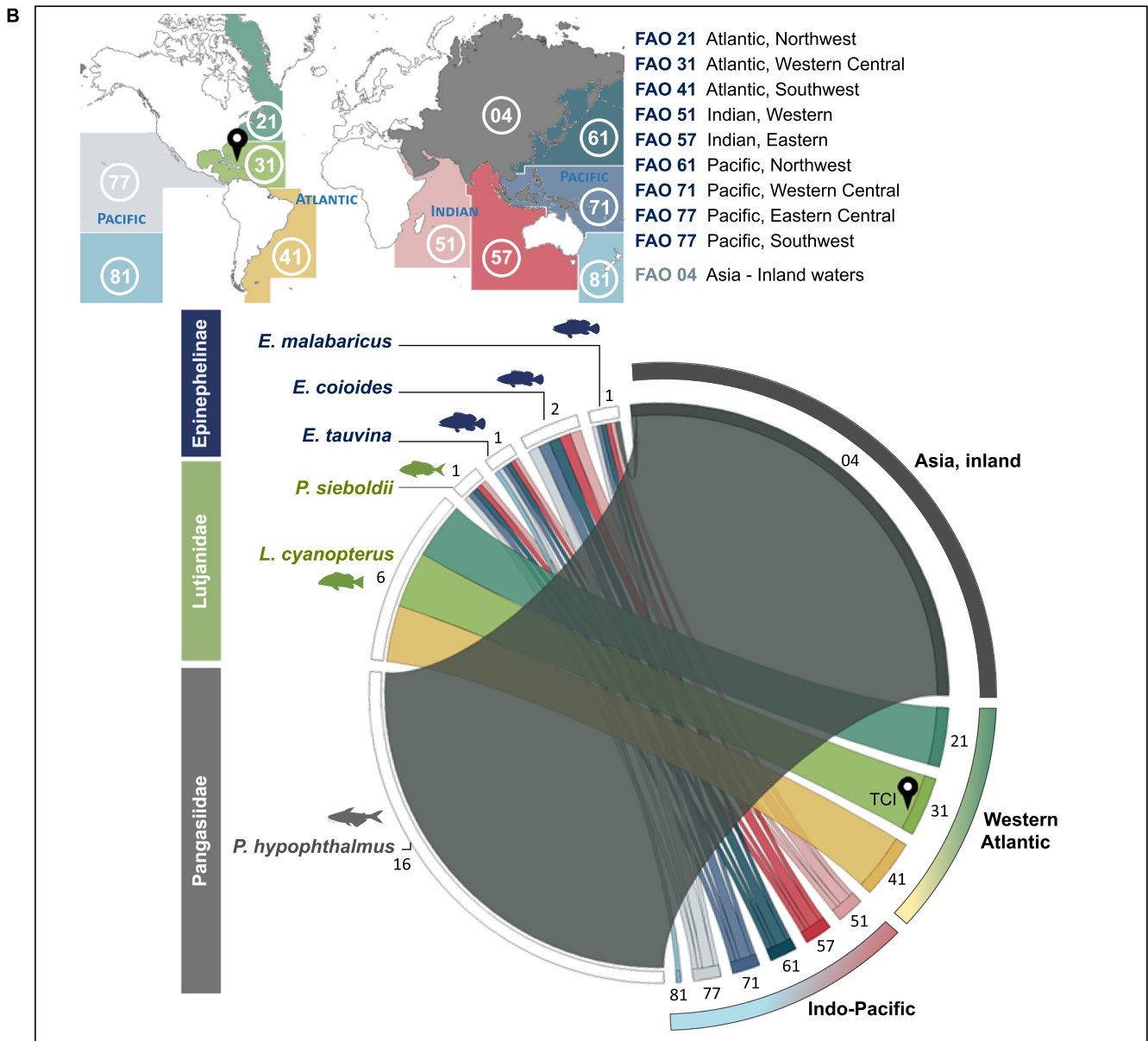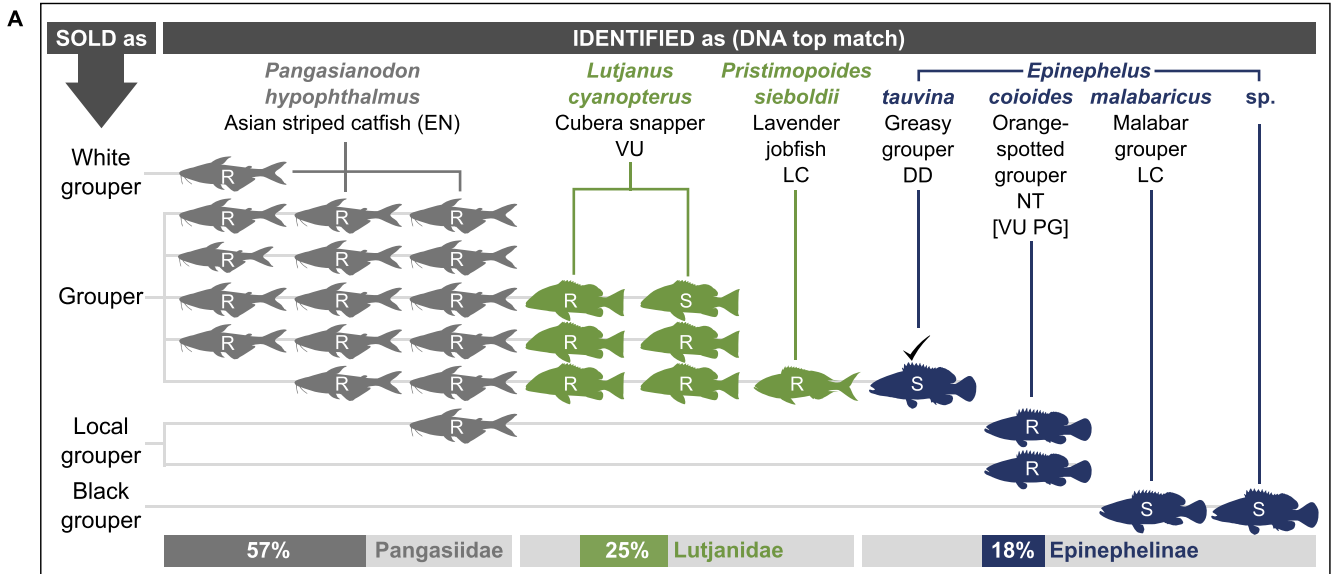
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Fig. 2. Top DNA matches and likely origins of 'grouper' samples sold in the TCI. (A) Shows the proportional assignment of samples to species and (sub)family levels, as well as the IUCN Red List status of genetically identified species. (B) Shows the proportions of identified species linked with the different FAO areas in which they natively occur. The top map indicates the FAO area boundaries, with the pin marking the relative position of the TCI. R = sample from restaurant; S = sample from store; DD = data deficient; LC = Least Concern; NT = Near Threatened; (EN) = Endangered in the wild; PG = Persian Gulf; 'tick' = labelled correctly. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)
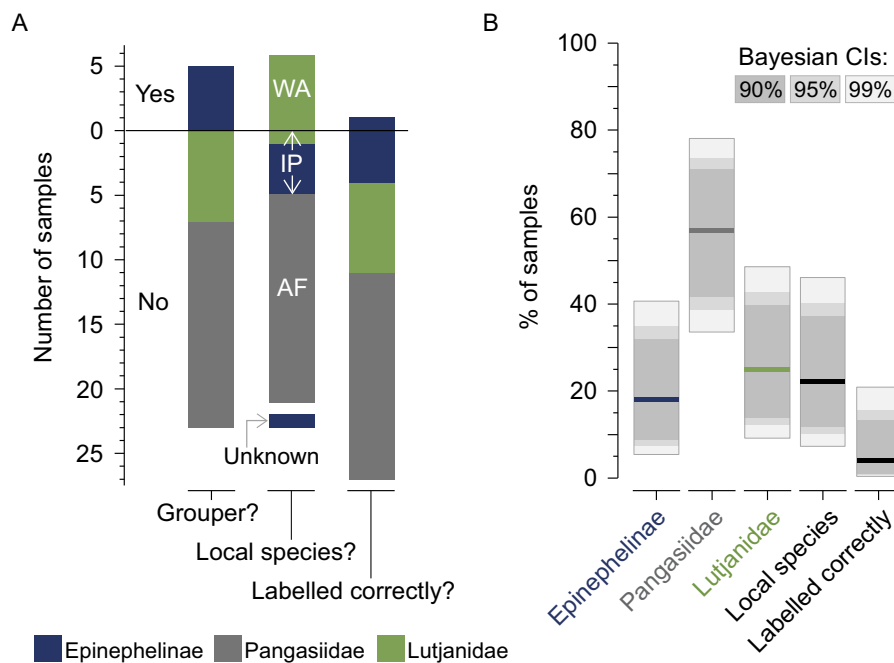

Fig. 3. 'Grouper' misrepresentation rates in the TCI. (A) Shows the number of samples sold as 'grouper' that were found through DNA analysis to belong to the grouper subfamily (Epinephelinae) or other families, to occur in local waters (i.e. Western Atlantic) or to derive from elsewhere, and to be labelled correctly or be mislabelled. (B) Shows the mode percentages of samples (coloured and black bars) that were confirmed as belonging to different families, as being species occurring locally (i.e. with distributions in the Western Atlantic), and as being labelled correctly. Bayesian confidence intervals are indicated with grey boxes (see insert for different intervals calculated). Samples were considered incorrectly labelled when identified as non-Epinephelinae spp., when sold under inaccurate common names, and when listed as 'local' but found to be imported. WA = Western Atlantic; IP = Indo-Pacific; AF = Asian freshwater (presumed to be farmed).

(*Pangasianodon hypophthalmus*) of the family Pangasiidae; a freshwater species massively farmed in South-East Asia (Fig. 2). The remaining seven samples (mode = 25%) were confirmed as Lutjanidae spp., including one as lavender jobfish (*Pristipomoides sieboldii*) which is found in the Indo-Pacific and six as cubera snapper (*Lutjanus cyanopterus*) which has a Western Atlantic distribution. Thus, of the 27 samples for which origin could be determined, only the latter 6 (mode = 22%) could be verified as potentially deriving from local TCI waters.

Overall, just one sample was labelled accurately (mode = 4%; 95% BCI: 0.4–15.5%), being advertised in a store as 'frozen grouper fillet' and returning a top species match with *E. tauvina* (Figs. 2 and 3). Two fillets sold in stores as 'black grouper' (a common name referring to *Mycteroperca bonaci* locally or *Hyporthodus mystacinus* elsewhere; Froese and Pauly, 2019) were rather assigned to *E. malabaricus* and *Epinephelus* sp. Two further samples described on restaurant menus as 'local grouper' were confirmed as orange-spotted grouper (*E. coioides*) from the Indo-Pacific and were consequently considered mislabelled by origin. Notably, an additional restaurant sample sold as 'local grouper' and identified as *P. hypophthalmus* was considered mislabelled by both species and origin.

4. Discussion

Contrary to what might be anticipated for a subtropical island nation with a rich complement of native Epinephelinae spp., the results of our study reveal a rather limited biodiversity in the TCI 'grouper' trade, including particularly low levels of Epinephelinae and local species in general. Instead, the data presented here highlight that this fish trade is largely being sustained through a heavy reliance on imported substitutes and concomitant high levels of mislabelling. From our total sample set, we identified just six species labelled as 'grouper', albeit from three different families. Approximately 82% of all analysed 'grouper' samples were confirmed as non-Epinephelinae spp., 78% were likely foreign imported species and 96% were mislabelled either by

species or origin. Albeit possibly elevated by the Nassau grouper closed season, this rate is among the highest reported for groupers globally (Fig. 4, see also Table A1, Suppl. Info). We also found that the species serving as substitutes for grouper in our study most closely resemble those identified in North America (i.e. *P. hypophthalmus*, Lutjanidae spp.), with less but some overlap with Europe (i.e. *P. hypophthalmus*) and no overlap with Belize (Fig. 4., see also Table A1, Suppl. Info.). In conflict with anecdotal reports or expectations, our DNA analyses did not detect Nassau grouper during its closed season, any other banned species (e.g. parrotfish) or undesirable ones, nor any local species other than cubera snapper. However, it is likely that more substitute species would have been detected with a larger sample size (Fig. A1, Suppl. Info.), and therefore the potential sale of such species cannot be excluded.

We discovered mislabelling at multiple levels in the TCI: freshwater farmed fish were sold as marine species; imported species were described on menus as 'locally caught' or 'fresh'; Lutjanidae spp. were sold as Epinephelinae spp. despite belonging to a different family of reef fishes; and Epinephelinae spp. were sold as 'grouper', but under misleading or inaccurate common names. A substantial portion of this mislabelling was almost certainly fraudulent. Specifically, the substitution of grouper with species other than Epinephelinae and the marketing of imported species as 'local' would both be considered 'false or misleading representation[s]' under the TCI Consumer Protection Ordinance 2016, and therefore constitute offences liable to fines. Although comparatively less frequent, some cases of mislabelling were possibly unintentional. For instance, selling *E. malabaricus* and *Epinephelus* sp. as 'black grouper', even though expected to constitute a local species (*M. bonaci*), might not be considered an infringement given that many Epinephelinae spp. have dark colouration (including *E. malabaricus*), the word 'local' was not expressly stated on the sample packaging, and the TCI has no mandatory standard market names. Therefore, it is possible that in those instances the vendors did not intend to deceive customers, either at the store in the TCI or at various
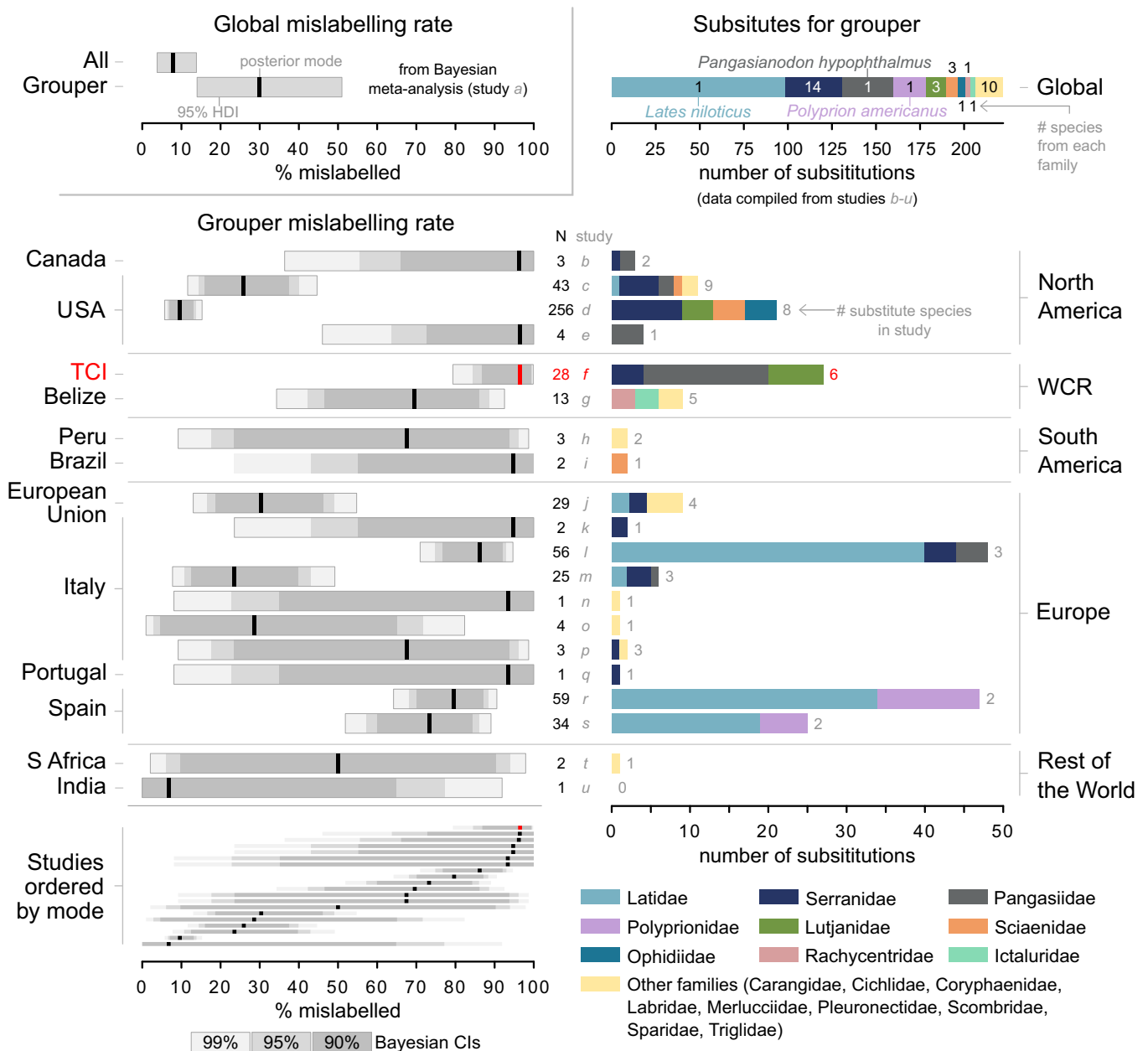
Fig. 4. The global reach of grouper mislabelling. The top left panel shows the global estimated average misrepresentation rates (posterior modes and 95% highest density intervals, HDIs) of all products tested ('All') and grouper from a Bayesian meta-analysis by Luque and Donlan (2019). The top right panel displays the substitutes for grouper discovered from 20 studies and analysis of 569 samples across the world. Panels below display mislabelling rates (modes and Bayesian confidence intervals) from these studies (left) and substitutes discovered (right). Studies are grouped by region and country, with mislabelling rates also summarised by increasing mode (bottom left panel). Horizontal black and red bars show mode mislabelling rate. Lower case grey and red letters indicate source studies: *a* – Luque and Donlan (2019); *b* – Levin (2018); *c* – Warner et al. (2013); *d* – FDA (2013); *e* – Wang and Hsieh (2016); *f* – our study; *g* – Cox et al. (2013); *h* – Marín et al. (2018); *i* – Staffen et al. (2017); *j* – European Commission (2015); *k* – Guardone et al. (2017); *l* – Di Pinto et al. (2015); *m* – Mottola et al. (2014); *n* – Cutarelli et al. (2013); *o* – Filonzi et al. (2010); *p* – Armani et al. (2016); *q* – Pardo et al., 2018; *r* – Asensio et al. (2009); *s* – Asensio (2008); *t* – Cawthorn et al. (2015); *u* – Nagalakshmi et al. (2016). Red bar and text highlight our study; WCR = Wider Caribbean Region; S Africa = South Africa. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

stages further back along the supply chain.

Studies from at least 15 countries across four continents have identified Pangasiidae spp. (primarily *P. hypophthalmus*) as cheaper substitutes for over 20 different species, including for 'grouper' in the USA, Canada, Italy and Spain (Table A4, Suppl. Info.). Nonetheless, in the context of a small island nation with a strong fishing heritage, the high prevalence of imported *P. hypophthalmus* in the TCI is surprising. Such findings differ from observations in Belize, where all substitutes for grouper were identified as species found locally (Cox et al., 2013).

However, the TCI fleet has traditionally focused on spiny lobster and queen conch rather than fish, and consequently restaurants and other outlets have become reliant on imported fish: in 2001, 40% of the 'grouper' (unverified as Epinephelinae) sold in restaurants was stated to be imported from Southeast Asia and Central America (Rudd, 2004).

The use of cubera snapper as a substitute for 'grouper' in restaurants and markets in the TCI is peculiar given the similar domestic demand, ex-vessel price, and cost of meals of both snapper and grouper locally. It is also worrying due to the 'vulnerable' status of L. *cyanopterus* (IUCN,

2020). However, because most TCI fishers sell their fish gutted, but otherwise whole (Rudd, 2003; MC own obs.), it is likely that mislabelling transpired at stages further along the supply chain. These substitutions might have been driven by a lack of locally caught grouper in the TCI, particularly during the Nassau grouper closed season. An alternative, but less likely explanation is that L. *cyanopterus* was imported and mislabelling originated outside the TCI.

On both global and regional markets, locally produced seafood is generally preferred over foreign counterparts due to consumer perceptions of superior quality, freshness and environmental stewardship, allowing a price premium to be charged (Fonner and Sylvia, 2015; Frash Jr et al., 2015). TCI restaurants value local sourcing (Bristow and Jenkins, 2018), and accordingly we observed numerous seafood items marketed as 'local' or 'locally caught', or with synonyms alluding to this (e.g. 'fresh', 'catch of the day', 'daily', 'Caicos', 'South Caicos', 'Salt Cay' etc.). However, no samples in our study were confirmed as species of grouper occurring locally, and even those explicitly sold as 'local grouper' were imported (two being assigned to E. *coioides* and one to P. *hypophthalmus*). A similar discrepancy between seafood declared to be 'local' has also been observed in the neighbouring Bahamas (Smith and Zeller, 2016).

During the study period, restaurants reported difficulty in sourcing grouper from local fishers. TCI restaurants have faced this problem for at least 15 years (Rudd, 2004). As tourist numbers continue to rise in the country (Turks and Caicos Statistics Department, 2019), it is even less likely that the local fisheries will be able to sustain the demand for grouper. This applies both in terms of the capacity of the fleet and its traditional focus on spiny lobster and queen conch, and in terms of the vulnerability of Epinephelinae to increased fishing pressure, especially targeting the critically endangered Nassau grouper. Low supply juxtaposed against high consumer expectations likely encourages the mislabelling of other species as 'grouper'. However, it should not be concluded that mislabelling protects local stocks, or that there is a net ecological benefit (see Mariani et al., 2017). Mislabelling promotes the perception that grouper is abundant which could jeopardise support for local management, a concern expressed for other species (Marko et al., 2004; Miller and Mariani, 2010). While the majority of products labelled as 'grouper' were actually freshwater farmed Asian catfish, those that were Epinephelinae were imported from the Indo-Pacific and thus fishing pressure on groupers is shifted to distant waters. Reliance on Indo-Pacific fisheries to supply the TCI market is problematic, regardless of whether this reduces fishing pressure on TCI stocks: E. *coioides* is 'near threatened' ('vulnerable' in its subrange of the Persian Gulf), and E. *tauvina* is 'data deficient' (IUCN, 2020); groupers in this region are frequently caught in data-scarce, poorly-managed, multispecies fisheries with no stock assessment and high rates of illegal, unreported and unregulated (IUU) fishing (Amorim et al., 2018); and groupers are generally highly vulnerable to fishing pressure (Sadovy de Mitcheson et al., 2013). This problem is not unique to TCI and substitution of 'local' species with Indo-Pacific grouper has been documented elsewhere (Warner et al., 2019).

Globally, fishers are not considered to be the main perpetrators of seafood fraud (Jacquet and Pauly, 2008). Similarly, in the TCI, local fishers do not appear to be the primary source or instigators of mislabelled 'grouper' into the supply chain. Instead, these fishers are probably among the indirect victims of this fraud. Falsely labelling cheap imported products as 'grouper' or as 'local' – whether occurring outside the TCI or along domestic supply chains – suppresses ex-vessel prices and gives fraudsters an unfair advantage over legitimate operators (Stiles et al., 2011; WWF, 2016). Mislabelling also erodes consumer confidence in domestic seafood, potentially decreasing demand for such products (Ropicki et al., 2010). These losses in revenue carry broad consequences for local fishing communities, as well as the national economy. In the TCI, this is particularly true for the island of South Caicos, where fisheries remain the dominant industry and fewer alternative revenue streams exist compared to Providenciales. However,

local fishers on both islands would benefit from efforts to eradicate mislabelling.

In the European Union (EU), advances in policy, monitoring, enforcement, and public awareness have been linked to notable reductions in the levels of seafood mislabelling (Mariani et al., 2015). Specifically, regulatory strategies aimed at improving seafood market transparency have included mandating minimum labelling requirements for fisheries products (i.e. declaration of pre-approved common name, scientific name, geographical origin, production method and fishing gear; Reg. [EU] 1379/2013), as well as expanding import controls and traceability legislation (Reg. [EU] 404/2011, European Community [EC] Regs 178/2002, 1224/2009). Developments in seafood authentication techniques (e.g. DNA barcoding, next-generation sequencing, isotope and elemental analysis), complemented with several EU-funded collaborative projects aimed at standardising and validating such techniques (e.g. Labelfish [www.labelfish.eu], FishPopTrace [https://fishpoptrace.jrc.ec.europa.eu]), have also provided a platform for enhanced supply chain monitoring and policy enforcement (Verrez-Bagnis et al., 2018). However, being one of the smallest countries in the world, the TCI government has limited capacity to address mislabelling with the same level of sustained intensity or technical sophistication as larger countries. In addition, with regards to the authenticity of imported seafood, the TCI may be largely restricted to the standards of exporting countries, with the primary supplier being the USA.

As a luxury tourist destination, seafood mislabelling in the TCI might be addressed more effectively through market-based strategies such as product integrity programmes and certifications which guarantee a combination of correct labelling, local production, and freshness. Among the plethora of eco-labels available worldwide, only few (e.g. the Marine Stewardship Council) require full net-to-plate traceability for their products, hence embedding authenticity in their certification scheme. The TCI small-scale fisheries targeting multiple species would best be readily assisted through seafood integrity programmes, which could be led by the tourist and hospitality (rather than public) sectors, which have the financial motivation to promote the quality of the seafood they provide and the ability to generate public awareness through publicising their initiatives. In Florida, where the problem of grouper substitution is widely documented, consumers have expressed willingness to pay premiums for grouper product integrity labels (Ropicki et al., 2010). While yet to be tested in the TCI, such initiatives appear to be well suited to the wealthy tourist customer base.

Although the high level of mislabelling identified in our study is worrying, it is unlikely to be representative of all seafood sold in the TCI. Species may be less frequently substituted if they are not typically sold as fillets but are more easily recognisable (e.g. small reef fishes and spiny lobster sold near-whole or as 'tails', respectively), or are species of lower value coupled with a more reliable supply. Furthermore, claims of local sourcing are also more likely to be authentic for queen conch and spiny lobster, the main targets of TCI fisheries and species that support relatively large domestic and export markets. Nonetheless, systems that can attest to the authenticity of all seafood will benefit consumers, fishers, the reputation of restaurants and other vendors, and ultimately fragile fish stocks and ecosystems.

CRediT authorship contribution statement

Marta C. Calosso: Conceptualization, Methodology, Investigation, Resources, Writing - original draft. **John A.B. Claydon:** Conceptualization, Methodology, Investigation, Formal analysis, Resources, Writing - original draft, Visualization, Funding acquisition. **Stefano Mariani:** Conceptualization, Methodology, Resources, Writing - review & editing, Funding acquisition, Supervision. **Donna-Mareè Cawthorn:** Methodology, Formal analysis, Investigation, Writing - original draft, Visualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2020.108557.

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