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Vague labelling laws and outdated fish naming lists undermine seafood market transparency in Canada

Donna-Mareè Cawthorn [a,*], Torie E. Murphy [b], Amanda M. Naaum [b], Robert H. Hanner [b]

[a] School of Biology and Environmental Sciences, Faculty of Agriculture and Natural Sciences, University of Mpumalanga, Corner of R40 and D725 Roads, Nelspruit 1200, South Africa
[b] Department of Integrative Biology, University of Guelph, Ontario, Canada

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ABSTRACT

Despite the expressed interest of Canadians in sustainable and comprehensively labelled seafood, the country's seafood labelling requirements remain scant and naming conventions in the Canadian Food Inspection Agency (CFIA) 'fish list' allow the grouping of multiple species under single 'umbrella' terms. Here, we test the extent to which CFIA listings reflect current market availability and conceal biodiversity, using the flatfishes as a model. Accordingly, we compared CFIA-listed flatfish species with those documented in Canadian import records, those in production records of Canada and its flatfish suppliers, as well as those identified in DNA-based market surveys conducted across Canada. Of the 43 flatfish species on the CFIA list, only three have consistently shown up in Canadian imports, production records and market surveys, whereas almost a third (n = 15) failed to appear in any of the latter over at least a decade. Species have been detected on the market that are absent from this list, while overfished and/or threatened taxa have been found concealed under vague generic terms. The list's many superfluous inclusions, outdated names, missing species and poor correspondence with trading partner's naming conventions are inconsistent with the legal tenets of Canadian policy to uphold fair market practices and consumer choice, and instead result in a system inundated by numerous paths of misinterpretation, misclassification and substitution. Moreover, Canada's official flatfish trade statistics lack sufficient taxonomic granularity to elucidate all species involved and track flatfish trade flows. Illuminating these loopholes should compel improvements in Canadian seafood labelling and traceability legislative frameworks.

1. Introduction

Fishes are the last wild animals that are hunted and consumed on a large scale. However, since the rise of industrial fisheries, global technological elaborations have resulted in increased fishing capacity and efficiency and, along with this, overfishing and depletion [1]. As the global need for protein has continued to escalate, efforts have progressively shifted to previously uncharted fishing grounds and an increasingly diverse range of 'new' fish species [2,3]. Today, this extensive wild biodiversity is being harvested and traded internationally at an unprecedented rate, underpinning staggeringly intricate seafood supply chain networks, whose traceability is becoming exceedingly difficult to monitor [4]. At a time when 60% of the world's assessed fish stocks are maximally exploited and 33% are overfished [5], the need for transparent trade and informed seafood choices has never been greater. Yet, consumers are routinely given little information on which to base their seafood selections. Apart from the European Union's (EU's) stringent seafood labelling regulations (Reg. [EU] 1379/2013; requiring declaration of the commercial designation, scientific name, production method, geographical origin and fishing gear), labelling laws in other countries are lax, often mandating little more than a 'common name' on seafood products [6]. The lack of taxonomic resolution and ongoing use of vague generic names in both trade records and market labels are among the most insidious impediments to seafood traceability and sustainability, as these practices lump multiple species under single 'umbrella' terms, create opportunities for substitution and fraud, and promote the inadvertent consumption of threatened or even illegally-harvested species [7–9].

With the world's longest coastline and access to three of the five oceans (Atlantic, Pacific and Arctic), Canada has a long and lucrative history of fishing, but also one marked by overexploitation and boom-and-bust cycles [10,11]. The notorious collapse of Atlantic Canada's

* Corresponding author.
E-mail address: Donna.Cawthorn@ump.ac.za (D.-M. Cawthorn).

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groundfish stocks in the early 1990s, including northern cod, brought an abrupt end to a 500-year-old fishery and drastically changed the face of the Canadian seafood industry [12,13]. By 1995, most Atlantic groundfish stocks were placed under directed-fishing moratoria, many of which have never been lifted [11]. Accordingly, Canada's marine fish landings plummeted by > 60% in less than a decade, from a peak of 1.3 million tonnes (t) in 1988 to ca. 500,000 t in the mid-1990s, and currently remain below the latter level [14] (Supp. Fig. S1). Canada's ranking as the world's largest seafood exporter concurrently dropped as marine fish exports decreased in the 1990s, with imports of these commodities climbing and surpassing exports in 2011 [15] (Supp. Fig. S2). While the fall of Atlantic groundfish illustrates the momentous costs of commodifying nature, these are just some of the many species to experience overfishing and declines in Canadian waters. In fact, only 24% of Canada's marine fish stocks are currently considered healthy, whereas the majority have a status of critical (16%), cautious (15%) or unknown (45%) [16].

Despite the expressed interest of Canadian consumers in local, sustainable and well-labelled seafood, they continue to be confronted with a wide range of poorly-labelled domestic products, as well as growing quantities of imports that reach the market via complex and opaque seafood supply chains [17,18]. Fuelling this problem is a lack of basic regulations for the labelling of seafood in Canada, with the only requirements being that a 'common name' appear on all retail products and that imports additionally include the country of last major transformation (i.e. not necessarily the geographical origin of the fish) [6]. Naming conventions are guided by the Canadian Food Inspection Agency 'fish list' [19], which contains ca. 900 species, but over 1,900 records due to the occurrence of multiple acceptable names for some species. Nonetheless, the CFIA provides no details on when the list was compiled or on the rationale for species inclusions. Moreover, due to the generic and ambiguous nature of the included common names, over 100 species may be grouped under a single name, and dozens of different names can be used for a single species. Although an obvious impediment to consumer choice, no studies have empirically tested the extent to which the CFIA listings reflect current market availability, whether this availability may be influenced by past or present overexploitation, and how this vague consumer-facing nomenclature might mask market biodiversity and the sale of overfished or otherwise threatened species.

Here, we tackle this important issue using one of the world's most valued groups of food fishes as a case study – the flatfishes (order Pleuronectiformes). This order comprises 14 families, 134 genera and over 800 species of mostly marine demersal fishes, characterised by their laterally compressed bodies and asymmetrical eye geometry, and including the popular halibuts, soles, flounders, plaice and turbots [20,21]. Although their fate was largely overshadowed by the demise of the iconic northern cod, several of these flatfishes were among the groundfish species to experience dramatic declines and moratoria in the 1990s [22–24]. A total of 39 flatfish species are reported to occur in Canadian waters; however, only 12 of these are considered commercially important [21]. Yet, the CFIA list includes 43 flatfish species and over 100 flatfish records (i.e. due to multiple acceptable names for certain species). Of these, 24 species may be collectively referred to as 'flounder', 22 as 'sole', six as 'turbot', three as 'plaice', two as 'halibut' and four as 'tonguesole', while over 50 additional names can be applied to one or more of these species [19]. Only 22 of the 39 species occurring in domestic waters are included on the CFIA list (Supp. Table S1). Given the historical exploitation and declining landings of flatfishes in Canadian and surrounding waters [14] (Supp. Fig. S1), it is essential to determine the level of correspondence between these species' listings and their actual market appearance. If the CFIA's flatfish listings were originally based on rates of production and market provision, then the absence of certain species from the Canadian seafood supply chain might indicate reduced supply or depletion in Canada's fishing jurisdiction or those of its flatfish supplier countries. Alternatively, if the former were not the basis for inclusion, then species absence might merely suggest the need for a more thoroughly formulated and up-to-date list of realistically available species. To this end, we compared the CFIA-listed flatfish species with those recorded in Canadian import records, those in the production records of both Canada and its top flatfish supplier countries, as well as those identified in this study and previous DNA-based market surveys conducted across Canada (Fig. 1). To reinforce these results, we also evaluated whether fluctuations in the long-term production and stock status trends of each CFIA-listed species might reflect in their diminishing provision and/or appearance in the Canadian seafood supply chain.

2. Materials and methods

2.1. Flatfish imports

Canadian flatfish import statistics were collated and compared for a 10-year period (2007–2016) using various data sources detailed below and in Fig. 1. This analysis period was selected because, at the time of analysis, most accessed databases included flatfish trade records only up to and including 2016. The focus was placed on traded volumes (tonnes, commodity weight [t, CW]) of three primary commodity groups, namely 'fresh or chilled fish', 'frozen fish' and 'fish fillets and other meat'. Preliminary explorations of Canada's officially-reported flatfish imports were conducted in the Food and Agriculture Organization's (FAO's) 'Fishery Commodities and Trade' database [15]. FAO records were filtered by selecting (i) 'Canada' under the 'country' search tab, (ii) 'imports' under the 'trade flow' tab, (iii) all flatfish species listed under the 'FAO major group – fish, fresh, chilled or frozen' under the 'commodity' tab, and (iv) the years 2007–2016 under the 'time' tab. However, since the FAO's trade statistics are unidirectional (i.e. no information given on origins of reported imports), more exhaustive investigations were required to elucidate the principal suppliers of Canada's flatfish imports and species involved. The United Nations Commodity Trade Statistics Database (UN Comtrade, http://comtrade.un.org) served as the main point of entry to access official international bilateral trade statistics for the study period, specifying 'Canada' as the 'reporter', 'all countries' as 'partners', 'imports' as the 'trade flow' and all relevant flatfish commodities listed at the most disaggregated six-digit level of the Harmonized System (HS-6) code (Fig. 1). Finally, since flatfish classifications at the HS-6 level are seldom species-specific, attempts were made to access more taxonomically-resolved data at the 8- or 10-digit tariff-line level from the International Trade Centre's (ITC's) Trade Map database (www.trademap.org).

Correspondence of the figures derived from the three statistical collections was verified by checking that the tariff-line data from Trade Map approximated the HS-6 recorded classifications in Comtrade, and by cross-referencing Comtrade totals with FAO totals. It should simultaneously be noted that although Canadian trade totals and bilateral HS-6 level data are respectively available from the Department of Fisheries and Oceans Canada (DFO) and Statistics Canada, the lack of commodity splitting in the former and the reporting only in value terms (Canadian or US dollars) in the latter made these data poorly comparable with the trade volumes obtained via the abovementioned three sources.

All retrieved import statistics were synthesised into a single dataset (see Supplementary Database S1), including the year, commodity code, commodity description, taxonomic classification, country of origin, trade volume (t CW) and trade value (thousand US$). Trade volumes were subsequently aggregated for the study period by supplier country and examined commodity, as well as overall.

2.2. Flatfish production statistics

Canada's officially-reported flatfish production records were obtained from the FAO's 'Global Production' database [14], with the relative contributions from capture fisheries and aquaculture being assessed in the FAO's individually collated 'Global Capture Production'

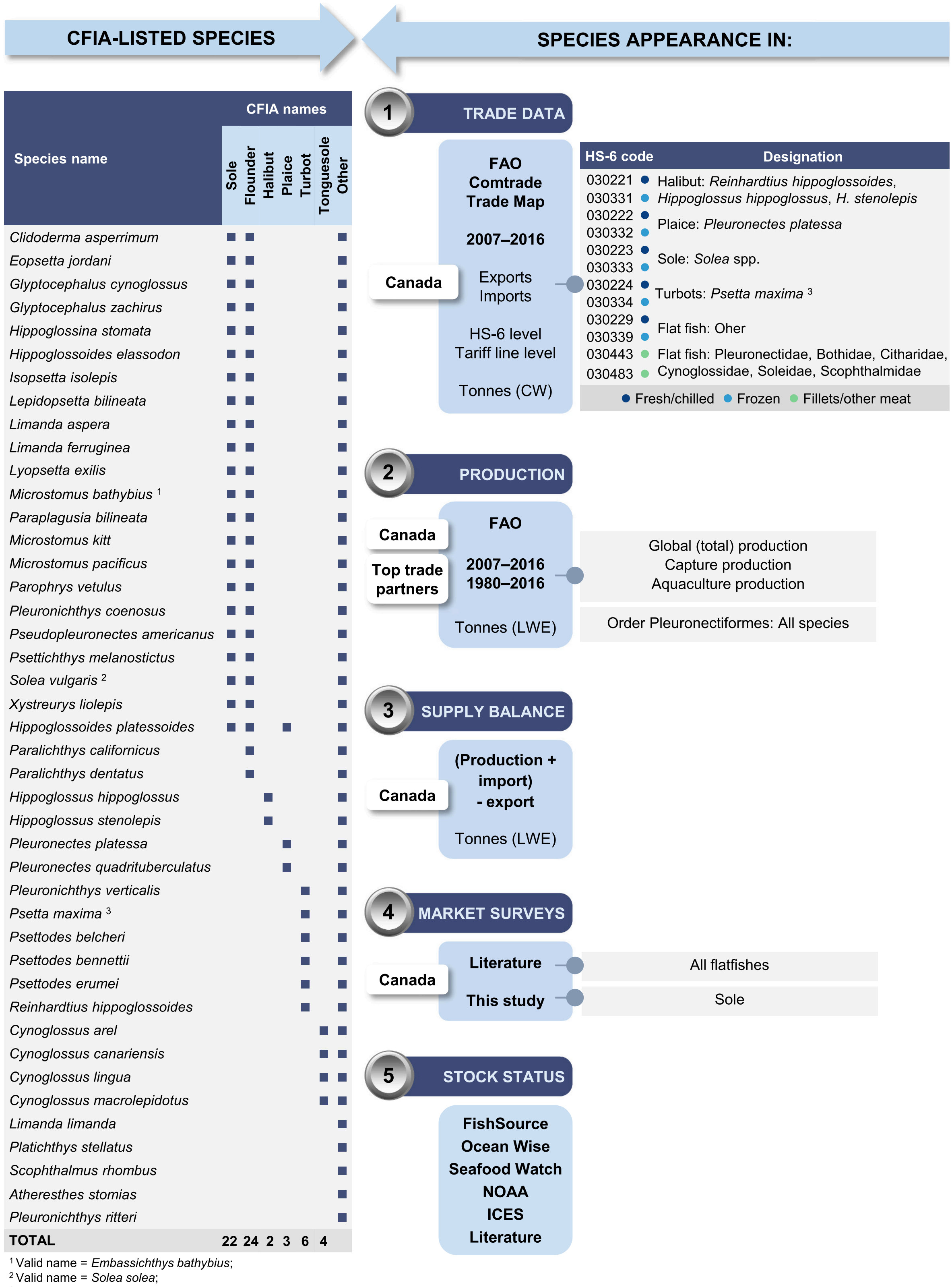

Fig. 1. Study design. Outline of sequential steps taken in investigating correspondence between flatfish species included on the CFIA list and those prospectively available to the Canadian market. The left-hand panel shows the 43 flatfish species appearing on the CFIA list and their CFIA-approved common names. The valid names for the CFIA-listed species were derived from the Integrated Taxonomic Information System (ITIS, www.itis.gov).
The right-hand panel includes the primary data sources, country records, time periods, commodities and HS-6 bases of the trade records evaluated for flatfish species occurrence. CW = commodity weight; LWE = live weight equivalent.

and 'Global Aquaculture Production' repositories (Fig. 1). Corresponding production records were also sought for Canada's top six flatfish suppliers, namely the United States (US), China, Sri Lanka, Mexico, Netherlands and India (each individually contributing ≥ 1% share of Canada's aggregate flatfish imports for 2007–2016; jointly comprising 95% of this share). The underlying assumption for this step was that the main flatfish species produced by each partner country would most likely appear in their respective exports to Canada. Within each FAO database, records were retrieved by selecting (i) Canada and the six designated suppliers under the 'country' search tab, (ii) all species in the order Pleuronectiformes under the 'taxonomic classification' tab, and (iii) 2007–2016 under the 'time' tab. Production volumes of each recorded flatfish species were aggregated by producer country for the period 2007–2016. Nonetheless, given that no flatfish production data could be sourced for Sri Lanka, the number of evaluated suppliers was reduced to five.

2.3. Canada's flatfish supply balance

To estimate Canada's flatfish supply balance for the study period (i.e. volumes of different flatfish commodities available to the local marketplace), Canadian flatfish export data were compiled in a similar manner to imports, with these volumes being subtracted from the combined production and import volumes of each relevant flatfish species or commodity grouping (Fig. 1). To promote comparability between traded volumes and production volumes, the commodity weights of imports and exports were converted to live weight equivalents (LWE) using conversion factors for 'fresh/chilled', 'frozen' and 'filleted' flatfish commodities [25].

2.4. Canadian flatfish market diversity

2.4.1. Literature review

Initial investigations into the diversity of flatfish species appearing on the Canadian market were performed via a comprehensive review of existing seafood authentication literature. Published and peer-reviewed records were explored in Google Scholar, Scopus and Science Direct using the following Boolean search string: ('Canada' OR 'Canadian') AND ('fish*' OR 'seafood') AND ('DNA' OR 'DNA barcoding' OR 'authentication' OR 'mislabel*' OR 'fraud' OR 'substitution'). A similar strategy was used to explore the 'grey literature' to identify applicable working papers and other unpublished materials. Captured literature sources were screened for relevance, retaining only those with detailed listings of flatfish species identified through Canadian market surveys.

2.4.2. DNA-based market survey – sole

To reinforce the species occurrence data obtained via literature review, an empirical DNA-based market survey of 'sole' products was carried out across Southern Ontario, Canada. 'Sole' was selected as the focus due to the large number of species (n = 22) listed under this generic term on the CFIA list (Fig. 1) and given the lack of exhaustive coverage on this 'group' in previous Canadian seafood authentication studies. A total of 50 samples sold with 'sole' in the description were obtained from retailers (supermarkets, fish shops, fish markets) in six cities: Brampton, Burlington, Cambridge, Guelph, Kitchener and Waterloo. Collected samples included fresh and frozen fillets or portions, and value-added products. Product labelling information was recorded at the point of sale (see also Supplementary Methods; Supp. Database S2).

Sample DNA was extracted with the DNeasy Blood & Tissue Kit (Cat. #69506, Qiagen, Toronto, ON, Canada) and a ~650 base-pair (bp) fragment of the cytochrome *c* oxidase I (COI) gene was amplified by polymerase chain reaction (PCR) using the barcoding primer cocktails, reaction mixtures and thermal cycling conditions from Ivanova et al. [26]. A full description of the molecular methods is given in the Supplementary Materials. PCR products were purified and bi-directionally sequenced at the University of Guelph Genomics Facility. Bi-directional contig assembly and quality editing were conducted with DNA Dragon Software (www.dna-dragon.com). Consensus sequences were subsequently queried in GenBank (www.ncbi.nlm.nih.gov), cross-referencing identification results in the Barcode of Life Database (BOLD, www.boldsystems.org) 'Species-Level' and 'Public Records' depositories. Additionally, consensus sequences were aligned, ambiguous sites were trimmed and a Kimura-2-parameter (K2P) Neighbour-Joining (NJ) tree was constructed with bootstrapping (Supplementary Methods; Supp. Fig. S3). For each sample, species identifications were assigned based on top matches of ≥ 98% across the three sequence databases and clustering positions in the NJ tree, but potential candidate species with < 2% divergence were also recorded (Supp. Database S2). The genetic species identifications and market names of the purchased samples were compared with the approved species listed as 'sole' on the CFIA list [19], cross-checking the valid names in FishBase [21].

2.5. Market availability versus historical production and stock status trends

To assess whether historical fluctuations in production or stock status of individual flatfish species might influence their availability to the Canadian market, a multi-step approach was taken. Firstly, long-term flatfish production records for Canada and its major suppliers were obtained by repeating the searches in Section 2.2, but by backdating the 'time' period to 1980–2016 and plotting production trends over this time series (Fig. 1). For each species identified in these historical records, additional data were sought on current and past production and stock status trends, management regimes and overall sustainability of the species in each respective source country. This additional data were mainly acquired via coordinated searches of official stock status reports, stock assessments, scientific literature and online resources (FishSource, www.fishsource.org; Canada's Ocean Wise programme, http://seafood.ocean.org; Monterey Bay Aquarium's Seafood Watch, www.seafoodwatch.org; the US National Oceanic and Atmospheric Administration's [NOAA's] fisheries website [27] and the International Council for the Exploration of the Sea [ICES] stock assessment database, www.ices.dk). Lastly, the amassed historical production and stock status data for each species were compared with the respective occurrences of the given species in Canadian import and market survey records.

3. Results and discussion

3.1. Data caveats

Any analysis that employs global data, derived via a range of third-party providers, is likely to be complicated by data quality issues. In this study, several such complications were encountered that require mention, given that uncertainties in the analysis almost entirely stem from data gaps. Firstly, while various sources of Canadian flatfish trade data exist, the records proffered by the DFO and Statistics Canada lack specificity and are poorly comparable with one another and with official global trade data repositories (i.e. Comtrade and FAO) (see also [28]). These shortcomings in the former national-level statistics necessitated a heavy reliance on the latter sources for investigating Canada's flatfish import and supply-balance composition. Nevertheless, despite extensive endeavours to obtain detailed trade records, the highly aggregated nature of Canada's publicly available flatfish import statistics precluded precise clarification of the species included. Most import records were reported only at non-specific HS-6 levels, with limited availability of detailed 8- or 10-digit tariff-line data. Although perusal of the production records of Canada's flatfish suppliers was anticipated to partially account for these gaps and predict the most likely species to appear in their supplies, these records were similarly poorly resolved in the case of India and Mexico, and completely absent in the case of Sri Lanka. Lastly, unlike the US NOAA that succinctly synthesises up-to-date data on stock status, sustainability and management of commonly harvested species, there is no single public source of information from which the current status of Canadian fish stocks can easily be discerned (see also [16]). Data on individual stocks are found in many different and often inaccessible report types scattered across the DFO website or elsewhere, making it difficult to ensure that all relevant information has been captured.

It is also worth noting the existence of some outdated taxonomy across these production and trade databases that may complicate the interpretation and presentation of our results. For instance, there has been a long history of confusion and debate around the valid scientific name for the turbot, with both *Psetta maxima* and *Scophthalmus maximus* being used interchangeably for the species in the fisheries literature and in major checklists and ichthyofaunas [29]. The 2017 revision of the HS nomenclature uses the synonym *P. maxima* for turbot, and the species is recorded as such in the FAO, Comtrade and Trade Map databases, as well as in the CFIA list (Fig. 1). Although this paper generally refers to *P. maxima* in order to reflect – and not contradict – how turbot is captured in official production and trade statistics, we acknowledge that the species would be more accurately described using the accepted name *S. maximus*.

3.2. Volumes and composition of Canadian flatfish imports

Canada's aggregate flatfish imports for 2007–2016 amounted to 82,815 t CW, with a mean ± standard deviation (SD) of 8,282 ± 1,824 t CW per annum (Fig. 2A). The US was by far the largest supplier of flatfishes to the Canadian market (ca. 47,000 t CW over the study period; 57% of Canada's aggregate import share), followed by China (ca. 26,700 t CW; 32% share), then Sri Lanka, Mexico, Netherlands and India (each 1–2% share), and then by 62 other countries providing the remaining small amounts. Poor taxonomic granularity was observed in Canada's flatfish import records, with just 17% of the volumes reported at the species level and only six different species being identifiable in the aggregate import pool (Fig. 2B). The majority (72%) of imports were rather classified under general group names (i.e. 'halibuts nei [not elsewhere included]', 'soles nei', 'turbots nei') and 11% of the volumes were merely recorded under the broad order-level category 'flatfishes nei (Pleuronectiformes)'.

'Fresh' and 'frozen' halibuts contributed over half of Canada's aggregate flatfish imports (> 42,000 t CW; 51% share) (Fig. 2B), the overwhelming bulk (97%) of which were supplied by the US and predominantly included 'fresh' products. Most of these imports (73%) were recorded only as 'halibuts nei', but smaller proportions of Pacific halibut (*Hippoglossus stenolepis*), Atlantic halibut (*Hippoglossus hippoglossus*) and Greenland halibut[1] (*Reinhardtius hippoglossoides*) were all identified in Canadian imports (in descending order of volume) when accessing data at tariff-line level. Commodities incorporated under the broad category 'flatfish – fillets and other meat' comprised the second largest import group (> 31,000 t CW; 38% share), 92% of which were traded frozen and 8% fresh, and with China being the main supplier. 'Flatfish – other', which refers to flatfishes other than halibuts, plaice, soles and turbots, contributed ca. 8% (~6300 t CW) of aggregate imports, being mostly derived from Sri Lanka, the US, Mexico and India. 'Fresh' and 'frozen' common sole (*Solea solea*), turbot (*P. maxima*) and European plaice (*Pleuronectes platessa*) jointly comprised ca. 3% of aggregate imports; however, larger quantities of these species may have been masked under other generic listings, e.g. misclassified under 'flatfish – other' or included in 'flatfishes – fillets and other meat'.

In addition to the supplies derived solely from partner countries, scrutiny of Comtrade and Trade Map records permitted identification of ca. 506 t CW of Canadian flatfish re-imports incorporated within the aggregated import total for 2006–2017 (i.e. contributing 0.6% of this total) (Fig. 2A,B). Approximately 70% of these re-import volumes comprised 'fresh' and 'frozen' halibuts, 11% constituted 'flatfishes – fillets and other meat', and the balance included smaller proportions of various other 'fresh' and 'frozen' flatfish commodities (Fig. 2B). Following Canada's official definition, these re-imports refer to goods of Canadian origin that are exported abroad and then re-enter Canada without being materially altered or substantially enhanced in value while away [31]. According to the United Nations, previously exported goods might be returned to the country of origin for several reasons, including: when materials are defective, when importers cancel orders or default on payment, when authorities impose import barriers, or when prices or demand in the country of origin render it worthwhile to bring materials back [32]. It is well known that a portion of Canada's domestically landed or farmed fish is exported to comparatively low-wage countries for processing, commonly China, and then re-imported into Canada [4,28]. Evaluation of Canadian flatfish export records available in Comtrade for 2007–2016 revealed that, as with imports, the US and China represented the two main export markets for Canadian flatfish for the study period (data not shown). In fact, both countries were net importers of 'fresh' and 'frozen' flatfish commodities from Canada, whereas China was by far a net exporter of processed flatfish 'fillets and other meat' to Canada. Such findings may support the notion of China being a processing centre for Canadian flatfish. Nonetheless, the implicit difficulties in tracking these product movements and disentangling exports or imports for processing from a pool of vague trade records render it impossible to evaluate the magnitude of this trade, as well as the extent to which it might be included in Canadian re-import figures.

3.3. Volumes and species in production

Fig. 3 shows the aggregate volumes of flatfish species produced by Canada for 2007–2016, as well as the corresponding volumes produced by its top flatfish suppliers. According to FAO statistics, Canada's flatfish production for the study period equated to 412,164 t LWE and averaged (± SD) 41,216 ± 4427 t LWE per annum (Fig. 3A), with these supplies exclusively deriving from capture fisheries. Flatfishes contributed 22% of Canada's total groundfish landings and 10% of its total marine fish landings (by weight) over this time (Supp. Fig. S1). Overall, 83% of the recorded flatfish landings were species-specific, whereas the rest (17%) were recorded at the order level (i.e. flatfishes nei, Pleuronectiformes). Of the 39 flatfish species occurring in Canadian waters, only eight of these were identified in Canada's aggregate production records, with Greenland halibut (*R. hippoglossoides*) comprising the largest volume (135,910 t LWE) and then yellowtail flounder (*Limanda ferruginea*) (61,374 t LWE) (Fig. 3A).

Considering Canada's top flatfish trading partners, the two predominant import suppliers, i.e. the US and China, were also the largest flatfish producers over the study period, generating > 3.0 million t LWE and > 1.1 million t LWE of flatfishes, respectively (Fig. 3B). The lower flatfish production volumes recorded for the Netherlands, India and Mexico may partially explain their smaller contributions to Canada's aggregate import share. Approximately 78% of the aggregate flatfish volumes produced by these five supplier countries came from marine capture landings, while 22% came from aquaculture. Capture landings contributed 100% of flatfish production in the US and India, and > 99% in Mexico and the Netherlands, whereas China's flatfish production was almost entirely (99%) derived from aquaculture. On average, the production records of Canada's suppliers were less resolved than those of Canada itself, with 77%, 11% and 12% of the total volumes recorded at the level of species, family and order, respectively. However, this taxonomic resolution differed widely by reporter country. Whereas > 99% and 94% of US' and Netherland's respective production records were species-specific, this extended to only 50% of China's records, and

[1] Referred to as 'Greenland turbot' in Canada (CFIA list), but 'Greenland halibut' is the official FAO name for *R. hippoglossoides*.

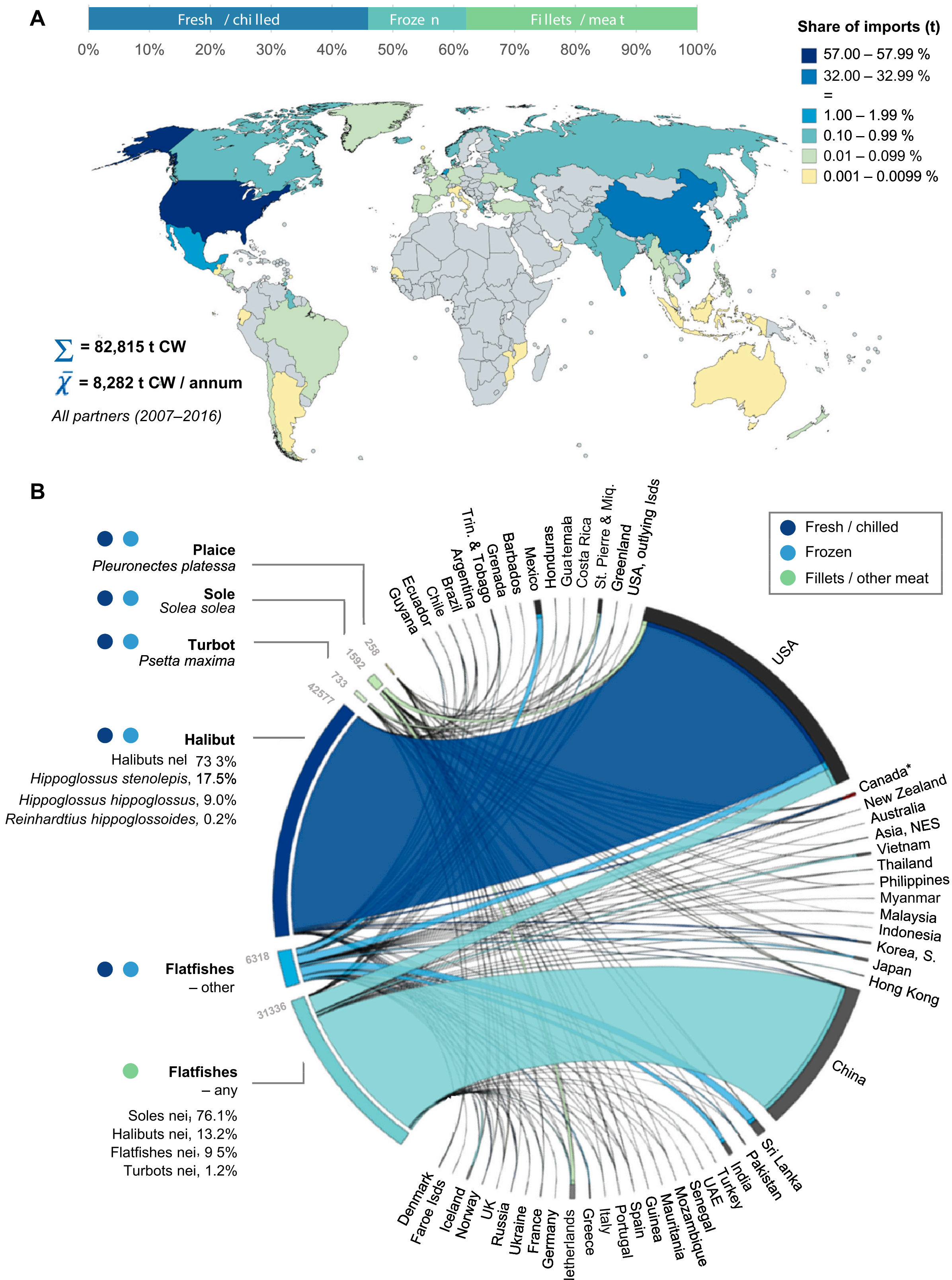

Fig. 2. Canada's reported flatfish imports from specified trading partners. (A) Shows the share of imports by partner country for the period 2007–2016, as well as aggregate and average totals for this time in t CW. (B) Shows the different flatfish commodity groups comprising Canada's flatfish imports from specified trading partners, aggregated for 2007–2016, in t CW. Import data were mainly derived from UN Comtrade and include 'fresh/chilled fish' of HS heading 0302, 'frozen fish' of HS 0303, and 'fillets/other meat' of HS 0304. 'Flatfishes – other' refers to commodities recorded under HS 030229 and 030339, which encompass flatfishes other than halibuts, plaice, soles and turbots. 'Flatfishes – any' refers to commodities under HS 030443 and 030483, which include any species from the families Pleuronectidae, Bothidae, Cynoglossidae, Soleidae, Scophthalmidae and Citharidae. Imports from countries totalling < 0.001% of the total import share over the study period are not shown. The top map was created using MapChart (https://mapchart.net) and the bottom figure was generated with Circos software [30]. t CW = tonnes commodity weight; * = re-imports.

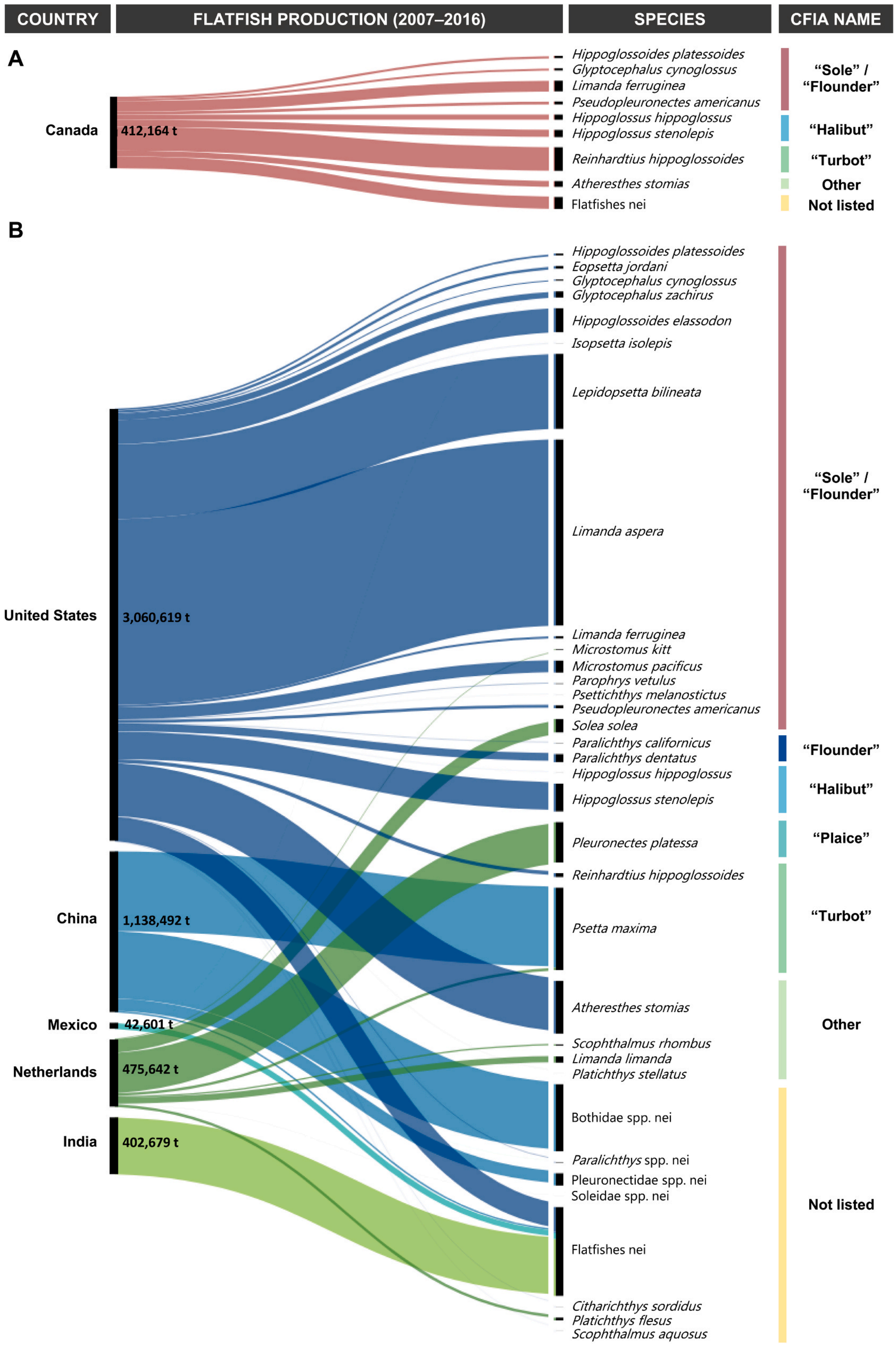

Fig. 3. Reported production of flatfishes by taxonomic classification level for 2007–2016. (A) Shows Canada's reported flatfish production and (B) shows the reported flatfish production of Canada's top flatfish supplier countries. Production data were collated from the FAO's 'Global Production', 'Global Capture Production' and 'Global Aquaculture Production' statistical collections and are in t LWE. The right-hand column shows the name allocated to each species in production as per the Canadian Food Inspection Agency (CFIA) fish list. t LWE = tonnes live weight equivalent.
No flatfish production data could be sourced from the FAO databases for Sri Lanka, Canada's third-largest flatfish supplier.

almost all of India's and Mexico's records were classified only at the order level. Overall, 30 flatfish species were identified in the production records of Canada's top suppliers, 26 of which appear on the CFIA list. The highest diversity of species was reported by the US (n = 22 species) and the Netherlands (n = 10 species). Yellowfin sole (*Limanda aspera*), turbot (*P. maxima*) and southern rock sole (*Lepidopsetta bilineata*) were the three species contributing most notably to the production volumes of Canada's trading partners, with *L. aspera* and *L. bilineata* coming exclusively from US capture fisheries and *P. maxima* deriving mostly from Chinese aquaculture.

3.4. Canada's flatfish supply balance

By calculating Canada's flatfish supply balance for 2007–2016, an aggregate volume of 331,200 t LWE of flatfishes, or ca. 33,000 t per annum, was estimated to have been available for local consumption (Supp. Fig. S4). Although absent from domestic production records, Canada's hefty imports of sole (*Solea* spp., mostly 'fillets'; Fig. 2) and minor associated exports, rendered this the most abundant (~124,000 t LWE) flatfish species group in the Canadian marketplace over the study period. Canada's total production of 'halibuts' (*R. hippoglossoides*, *H. stenolepis* and *H. hippoglossus*) for 2007–2016 equated to ca. 207,000 t LWE, however, even with their sizable halibut imports, Canada's net exports of these commodities meant that ca. 122,000 t LWE remained for domestic consumption (Supp. Fig. S4). Furthermore, following exports, ca. 53,000 t LWE of non-specified flatfishes (flatfishes nei), 41,000 t LWE of flounders and 13,000 t LWE of American plaice (*Hippoglossoides platessoides*) were theoretically available for domestic consumption over the study period. Negative supply balances were calculated for turbot (*P. maxima*) and European plaice (*P. platessa*) (i.e. greater exports than imports, with no reported production). Possible explanations for these findings are that some level of import and/or production of these species was unreported or masked under generic commodity classifications, or that the associated export data were inaccurate.

3.5. Canadian flatfish market diversity

3.5.1. Literature surveys

Comprehensive literature review identified seven research papers that included detailed records of flatfish species detected on the Canadian market (Table 1). All seven were published during or after the study period (2007–2016) and utilised DNA barcoding as the basis for species authentication. These combined literature records identified a total of 18 flatfish species that have been found in the Canadian marketplace, although the frequency of species occurrence varied both within and between studies (see Section 3.6).

3.5.2. Current market survey – sole

DNA barcoding results for 'sole' products collected across Southern Ontario are summarised in Table 1 and presented in full in Supp. Database S2. Of the 50 samples tested, 44 yielded interpretable COI barcodes, four did not return reliable matches in GenBank or BOLD (i.e. no match or < 98% sequence similarity) due to poor quality sequences, and two failed to amplify with all barcoding primer cocktails utilised. DNA degradation or the presence of PCR inhibitors were the most probable explanations for amplification failure [4].

For the 44 samples delivering interpretable sequences, explicit identifications were made for 38 samples, with six different flatfish species being detected and yellowfin sole (*L. aspera*) the most common among these. The remaining six samples showed overlapping barcodes between *Hippoglossoides elassodon* and *H. robustus* (n = 5), or between *H.*

Table 1
The frequency of occurence of different flatfish species found in various Canadian seafood market surveys and in this study.

Study	Literature								This study	Grand total
	1	**2**	**3**	**4**	**5**	**6**	**7**	**Total**		
Peer-reviewed	Yes	Yes	Yes	No	No	No	Yes		N/A	
DNA barcoding	Yes	Yes	Yes	Yes	Yes	Yes	Yes		Yes	
Region	Canada	Vancouver, Toronto, Gatineau, Montreal, Quebec	Ontario	Canada	Ottawa	Halifax, Ottawa, Toronto, Victoria, Vancouver	Vancouver		Ontario	
Species			**Number identified**							
Hippoglossus stenolepis		18	21	29	4	12	2	**86**		**86**
Limanda aspera	3		12	30	2	4		**51**	24	**75**
Microstomus pacificus	1	5	1	38		3		**48**	3	**51**
Hippoglossus hippoglossus	2	3	1	1	3	20		**30**		**30**
Lepidopsetta polyxystra			7	4		1	2	**14**	7	**21**
Hippoglossoides elassodon	1		1	2	2	3		**9**	5	**14**
Lepidopsetta bilineata	1		6		2	2		**11**		**11**
Limanda ferruginea				9				**9**		**9**
Solea solea			2		1	5		**8**		**8**
Reinhardtius hippoglossoides	2	1				3	2	**8**		**8**
Parophrys vetulus			3	4				**7**		**7**
Glyptocephalus cynoglossus				2		1		**3**	1	**4**
Eopsetta jordani						3		**3**		**3**
Paralichthys dentatus	1					1		**2**		**2**
Pseudopleuronectes americanus	2							**2**		**2**
Paralichthys californicus						1		**1**		**1**
Paralichthys olivaceus		1						**1**		**1**
Hippoglossus platessoides			1					**1**		**1**
Pleuronectes platessa									1	**1**
Pleuronectes quadrituberculatus									1	**1**

Data sources: 1: [33]; 2: [34]; 3: [35]; 4: [18]; 5: [36]; 6: [37]; 7: [4].

Table 2
Historical flatfish production trends for Canada and its top flatfish suppliers for 1980–2016. Solid lines are capture landings, dotted lines are linear trend lines and dashed lines indicate aquaculture production (see China's *Psetta maxima* production). CAN = Canada; USA = United States of America; CHN = China; MEX = Mexico; IND = India; LKA = Sri Lanka; NLD = Netherlands.

	CANADA	TOP SUPPLIERS
	CAN	USA, CHN, MEX, IND, LKA, NLD
	TONNES / YEAR (1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015)	TONNES / YEAR (1980, 1985, 1990, 1995, 2000, 2005, 2010, 2015)
Hippoglossus stenolepis (Pleuronectidae)	40000; 20000; 0; R^2 = 0.0047	40000; 20000; 0; R^2 = 0.0013
Hippoglossus hippoglossus (Pleuronectidae)	10000; 0	10000; 0
Reinhardtius hippoglossoides (Pleuronectidae)	40000; 20000; 0; R^2 = 0.4505	40000; 20000; 0; R^2 = 0.2765
Hippoglossoides platessoides (Pleuronectidae)	80000; 40000; 0; R^2 = 0.7598	80000; 40000; 0; R^2 = 0.7179
Glyptocephalus cynoglossus (Pleuronectidae)	10000; 0; R^2 = 0.6319	10000; 0; R^2 = 0.5859
Limanda ferruginea (Pleuronectidae)	40000; 20000; 0; R^2 = 0.2138	40000; 20000; 0; R^2 = 0.5434
Pseudo-pleuronectes americanus (Pleuronectidae)	20000; 10000; 0; R^2 = 0.4376	20000; 10000; 0; R^2 = 0.7482
Solea vulgaris* (Soleidae) * valid name = *Solea solea*		20000; 10000; 0; R^2 = 0.246
Pleuronectes platessa (Pleuronectidae)		80000; 40000; 0; R^2 = 0.5306
Psetta maxima† (Scophthalmidae) † valid name = *Scophthalmus maximus*		80000; 40000; 0; R^2 = 0.6883
Limanda aspera (Pleuronectidae)		180000; 90000; 0; R^2 = 0.0904
Hippoglossoides elassodon (Pleuronectidae)		20000; 10000; 0; R^2 = 0.6244
Atheresthes stomias (Pleuronectidae)	40000; 20000; 0	40000; 20000; 0; R^2 = 0.7451
Microstomus pacificus (Pleuronectidae)		10000; 0
Lepidopsetta bilineata (Pleuronectidae)		80000; 40000; 0; R^2 = 0.5895
Paralichthys californicus (Paralichthyidae)		10000; 0
Paralichthys dentatus (Paralichthyidae)		20000; 10000; 0; R^2 = 0.383
Parophrys vetulus (Pleuronectidae)		10000; 0
Eopsetta jordani (Pleuronectidae)		10000; 0
Isopsetta isolepis (Pleuronectidae)		10000; 0
Platichthys stellatus (Pleuronectidae)		10000; 0
Psettichthys melanostictus (Pleuronectidae)		10000; 0
Glyptocephalus zachirus (Pleuronectidae)		10000; 0; R^2 = 0.6843
Limanda limanda (Pleuronectidae)		10000; 0; R^2 = 0.1398
Microstomus kitt (Pleuronectidae)		10000; 0
Scophthalmus rhombus (Scophthalmidae)		10000; 0

dubius and *H. robustus* (n = 1). According to the CFIA list, 34 samples were correctly labelled as 'sole'. Aside from these, two samples identified as *P. platessa* and *P. quadrituberculatus* were deemed mislabelled, given that the approved CFIA designations for the former are 'plaice', 'dab' or 'roughback', and those for the latter are 'plaice' or 'Alaska plaice'. These flatfish mislabelling cases are lower in frequency and potentially more subtle than those found in previous Canadian seafood authentication studies (e.g. [4,37]). However, they still illustrate the propensity for nomenclature confusion and/or breakdowns in traceability of seafood supply chains feeding Canada's markets. One further 'fresh' fillet sample produced a barcode match with *Shewanella baltica* – a hydrogen sulphide-producing bacterium associated with fish spoilage. Although several *Shewanella* spp. have been implicated in human infections, the pathogenic potential of *S. baltica* remains uncertain [38]. Nevertheless, such results demonstrate the utility of DNA barcoding for detecting such organisms in seafood.

3.5.3. CFIA list – missing species, outdated names and inconsistencies

The labelling accuracy of two species found in market surveys – northern rock sole (*Lepidopsetta polyxystra*) and bastard halibut (*Paralichthys olivaceus*) – could not be evaluated against the CFIA's approved common names due to the absence of these species from the list [19]. In particular, the widespread detection of *L. polyxystra* (i.e. five studies, 21 records of occurrence overall) suggests that the CFIA list is not reflective of all commonly available flatfish on the Canadian market. Notably, 'sole' is listed as an acceptable market name for *L. polyxystra* on the US Food and Drug Administration's (FDA's) 'seafood list' [39], highlighting inconsistencies in seafood naming conventions of the two countries. Closer examination of these two seafood naming lists revealed many anomalies (Supp. Table S2), with only 13 of the 43 CFIA-listed flatfish species sharing identical names with those on the FDA list. The remaining 30 species all differ from the FDA list in terms of the acceptable market names or approved common names applied. Considering the strong seafood trade relationships between Canada and the US [15,28], including in flatfishes, such naming incongruities serve only to exacerbate confusion, promote unintentional or deliberate mislabelling and potentially distort trade and market statistics [8,9,33]. These findings lend support to calls for the revision and better harmonisation of international seafood naming lists, which would likely aid in reducing labelling complexities and separating out economically-motivated substitutions from miscommunications arising through regional nomenclature or outdated lists [4,9,35].

The inclusion of invalid species names on the CFIA list further undermines its usefulness and is incongruous with the CFIA's statement that "scientific names are verified with the Integrated Taxonomic Information System (ITIS)" and that "the fish list will be updated accordingly as…changes (to the scientific name of a species) are known" [40]. More specifically, common sole (*S. solea*) has been detected in three market surveys (Table 1), but the CFIA list still refers to the outdated synonym for the taxon, i.e. *S. vulgaris*. This oversight has generated confusion in the correct labelling and extent of mislabelling of sole products in Canada [35,37]. Although not detected in market surveys, the CFIA list also refers to deepsea sole and turbot as *Microstomus bathybius* and *Psetta maxima*, respectively, whereas the valid names for these taxa are *Embassichthys bathybius* and *Scophthalmus maximus* [41].

3.6. Market availability versus historical production and stock status trends

Historical flatfish production trends for Canada and its top flatfish suppliers are illustrated in Table 2, which covers all CFIA-listed species for which production data could be sourced. For both Canada and its main suppliers, the species composition of the long-term records (1980–2016; Table 2) was identical to that found in the shorter study period (2007–2016; Fig. 3). Fig. 4 provides a summary of the appearance of individual CFIA-listed flatfish species in historical production records, as well as in Canadian import records and market surveys. A detailed account of long-term stock status and sustainability indicators for the individual species is additionally provided in Supp. Table S3. The main findings and anomalies identified in Fig. 4 are discussed below, in the context of these production and stock status trends (Table 2, Supp. Table S3).

3.6.1. Wide supply chain appearance

Of the 43 flatfish species on the CFIA list, only three (Pacific halibut – *H. stenolepis*, Atlantic halibut – *H. hippoglossus* and Greenland halibut – *R. hippoglossoides*) have consistently appeared in Canadian import records, in historical production records of both Canada and its trading partners and have been detected in at least half of the Canadian market surveys (Group A – Fig. 4). It is, however, notable that Pacific and Atlantic halibuts have been detected in more market surveys and at higher frequencies than Greenland halibut (Table 1). Nonetheless, the demonstrated consumer-facing availability of these species is largely consistent with the considerable 'halibut' supply balance calculated for Canada (Supp. Fig. S4), which in turn may partially stem from the generally favourable status of the stocks in Canadian waters (Supp. Table S3). Canada's Pacific halibut population off British Columbia is considered healthy, well managed and not overfished [42]. Although intense overfishing contributed to the collapse of Atlantic halibut on the Scotian Shelf and southern Grand Banks in the early 1990s, the population rebounded by 2009 under strict management measures, and landings have steadily increased [43] (Table 2). The Canadian Pacific halibut fishery and re-established Atlantic halibut fishery are now certified as sustainable by the Marine Stewardship Council [44]. Canadian landings of Greenland halibut decreased from their peak in the early 1980s following the introduction of total allowable catches (TACs) to the fisheries, but these harvest limits have subsequently helped to promote stability in domestic stock biomass and landings (Table 2, Supp. Table S3).

The situation is somewhat different in the US, Canada's largest 'halibut' supplier, where the precipitous collapse of the Atlantic halibut fishery stands in stark contrast to the relatively successful management of Pacific and Greenland halibut (Supp. Table S3). With the transition of Atlantic halibut from a worthless bycatch to a marketable product in the 1800s, a series of localised depletions in US waters soon escalated to outright commercial extinction by the turn of the 20th century, and US Atlantic halibut stocks have never recovered from this collapse [10,45]. Atlantic halibut is listed as a 'species of concern' under the US Endangered Species Act (1973) and has been under a directed-fishing moratorium since 1999, with US landings over the historical time series representing a mere 2% of the volumes taken in Canadian waters [14] (Table 2; Supp. Table S3).

3.6.2. Limited market availability, limited harvests

Four species referred to as 'sole' / 'flounder' on the CFIA list (American plaice – *H. platessoides*, witch flounder – *G. cynoglossus*, yellowtail flounder – *L. ferruginea* and winter flounder – *P. americanus*) have appeared in production records of Canada and its flatfish suppliers, but not in Canadian import records, and have been detected in few Canadian market studies and in low overall numbers (Group B – Fig. 4; Table 1). Their limited market appearance may be attributed to generally poor stock status and restricted harvests in Canadian and surrounding waters (Supp. Table S3). Canadian and US landings of American plaice, witch flounder and yellowtail flounder have shown similar fluctuations over the historical time series, with relatively high catches in the early 1980s, general declines in the late 1980s and outright collapses in the 1990s (Table 2). The American plaice fishery off Newfoundland's Grand Banks was once the largest flatfish fishery in the world, while also being the most important one in the Gulf of St. Lawrence (GoSL). However, ongoing directed-fishing moratoria on all Newfoundland/Labrador (NL) American plaice stocks since the mid-1990s have restricted Canada's overall landings to ca. 1% of historical

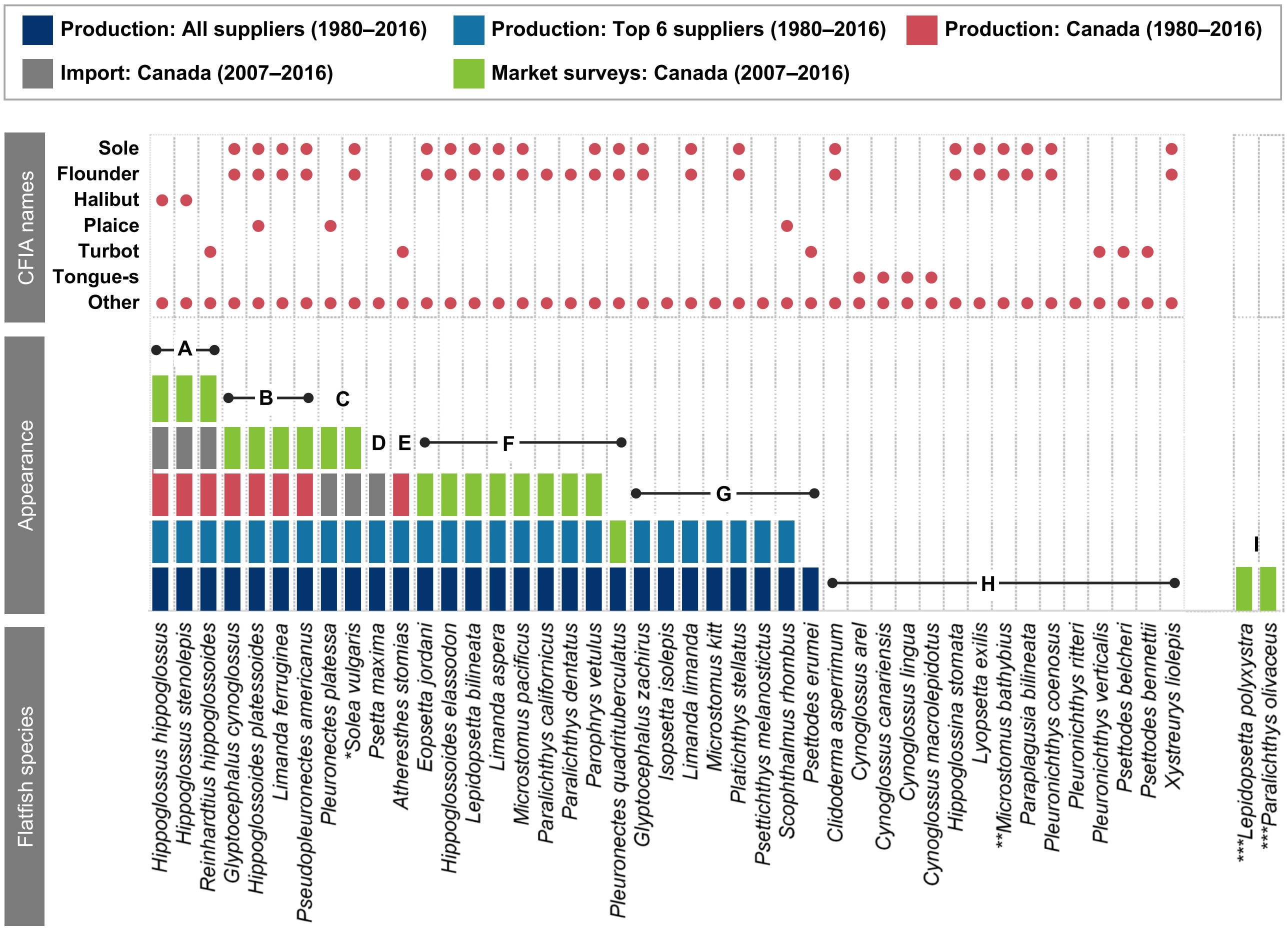

Fig. 4. CFIA flatfish listings versus actual species detection. The top panel shows the CFIA-approved common names for the 43 included flatfish species. The bottom panel provides a summary of the individual species identified in the historical production records of Canada and its flatfish suppliers, in Canadian import records and in Canadian market surveys. Species are grouped (A–I) according to their patterns of appearance in the evaluated records. Tongue-s = tonguesole; * valid name is *Solea solea*; ** valid name is *Embassichthys bathybius*; *** not included on CFIA fish list.

levels [24]. American plaice populations in NL and the Canadian Maritimes are at critical levels [16] and are classified as 'threatened' by the Committee on the Status of Endangered Wildlife in Canada [24].

The 1990s also saw similar moratoria being declared for witch flounder stocks on the Grand Banks and off Labrador/northeast Newfoundland, and for yellowtail flounder on the Grand Banks [22,23]. After four years of moratorium, the biomass of Grand Banks yellowtail flounder had quadrupled, the fishery was re-opened, and the Grand Banks yellowtail founder trawl was MSC certified in 2010 [22,44]. Nonetheless, the Grand Banks population is likely the only of Canada's three managed yellowtail flounder populations to be in good condition (Supp. Table S3). The moratorium on southern Grand Banks witch flounder was lifted in 2014 but remains in place for the Labrador/northeast Newfoundland stocks, with most post-1995 catches from these areas representing low levels of bycatch from other fisheries [23]. The GoSL witch flounder stock is in a critical state and subject to low TACs [16] (Supp. Table S3). Moreover, witch flounder and all three yellowtail flounder stocks in US waters are in a poor condition and considered overfished, with strict harvest limits to allow stocks to rebuild [46]. The stock status of winter flounder in the Canadian Maritimes is uncertain due to a lack of formal assessments, but catches are limited by quotas and have declined since the 1990s (Table 2). US winter flounder stocks have experienced severe declines and are at low levels, with current US landings representing ca. 5% of those recorded in the early 1980s (Table 2; Supp. Table S3).

3.6.3. *Imported, but largely absent from the market*

Canada's substantial imports and high apparent market availability of sole (*Solea* spp.) (Section 3.4; Supp. Fig. S4) is seemingly at odds with the relatively low detection of these species on the Canadian market (Table 1; Group C – Fig. 4). Conversely, although European plaice (*P. platessa*) and turbot (*P. maxima*) appeared in Canadian imports during 2007–2016 (Fig. 2), the detection of the former in only one market survey (this study) and the latter in no surveys (Table 1) does well coincide with the negative supply balances calculated for these species (Section 3.4; Supp. Fig S4). Review of the stock status trends of *Solea* spp., *P. platessa* and *P. maxima* both globally [47] and in Canada's supplier countries (Supp. Table S3) did not reveal any imminent threats to the populations or species. In fact, *P. platessa* has reportedly recovered from overfishing in the 1970s–1980′s and global landings have been rising since the turn of the 21st century [14,47]. Global *P. maxima* harvests have similarly increased in step with increasing aquaculture production of the species. It is plausible that Canada might serve as a transit country for the trade in these species or that they may be imported for processing and then re-exported, with both scenarios potentially explaining their scant market appearance, yet neither being confirmable from the currently available Canadian trade data.

3.6.4. *No reported domestic production or imports, but present on the market*

Nine flatfish species have appeared in the historical production records of Canada's flatfish suppliers and have been detected at varying rates in Canadian market surveys, but have neither shown up in

Canadian production records nor in imports (Group F – Fig. 4). Such findings suggest that some level of domestic production or import of these species was either unreported or masked under generic commodity classifications, and it is notable that several of these species occur in Canadian waters (Supp. Table S1). The high market detection rates of yellowfin sole (*L. aspera*) and Dover sole (*Microstomus pacificus*) (Table 1) are prospectively related to their good stock conditions in US waters (i.e. not overfished, not undergoing overfishing, some MSC-certified fisheries), as well as the substantial US catches in the case of yellowfin sole (Table 2; Supp. Table S3). Yellowfin sole is the target of the largest flatfish fishery in the US [27], generating landings of $> 100,000$ t per annum over the last decade (Table 2, Supp. Table S3). US Dover sole landings were only recorded by the FAO from 1997 onwards [14] but have since averaged ca. 8,000 t per annum. Dover sole is also reportedly caught in commercial trawl fisheries off British Columbia [48]; however, these landings are not specifically enumerated in Canada's official historical production records. Flathead sole (*H. elassodon*) and southern rock sole (*L. bilineata*) have been detected at moderate levels in Canadian market surveys, which presumably also coincides with their favourable stock status and relatively high catches in US waters over the last decade (Table 2, Supp. Table S3). Although not itemised in Canada's official production records, southern rock sole is known to be a commercially important component of the flatfish trawl off British Columbia, where landings have fluctuated from 400 to 3,500 t per annum since 1980 [49].

Summer flounder (*Paralichthys dentatus*), California flounder (*Paralichthys californicus*), English sole (*Parophrys vetulus*) and petrale sole (*Eopsetta jordani*) have been detected only sporadically on the Canadian market (Table 1), likely in accord with their rather low catches in US waters over the last decade (Table 2). Summer flounder is one of the most highly prized commercial and recreational fish species along the US Atlantic coast. US commercial harvests mostly exceeded 10,000 t per annum in the 1980s but declined to record lows in the 1990s and have since remained below historical peaks under TAC management (Table 2). While not currently considered overfished, US summer flounder stock abundance is below target levels and overfishing is still occurring [27]. Substantial levels of illegal and unreported summer flounder catches are likely contributing to this overfishing [50]. US catches of California flounder, English sole and petrale sole were only reported by the FAO from the late 1990s but are known to have been taken before this time (Supp. Table S3). Landings of all three species declined during the 2000s, with those of California flounder and English sole remaining low due to a combination of harvest controls and gear restrictions [27]. The central California stock of California flounder is in good health, whereas the southern California stock is depleted to 14% of its unexploited biomass, although biomass has remained relatively constant since the 1970s [51]. English sole populations off the US West Coast and Gulf of Alaska (GoA) are not overfished nor subject to overfishing. The marked declines in US petrale sole catches in the late 2000s may be partially attributed to the 'overfished' status of the West Coast stock. However, this stock was rebuilt by 2015 and landings have since increased [27].

3.6.5. Canadian market no-shows

One species – arrowtooth flounder (*A. stomias*) – occurred in the production records of both Canada and its main flatfish suppliers, but was not detected in Canadian import records or in any market surveys. A further eight species appeared only in supplier's production records while failing to show up in Canadian production records, imports and market surveys (Group G – Fig. 4). The apparent market absence of arrowtooth flounder may partially stem from Canada's low landings of the species over most of the historical time series (i.e. < 200 t per annum from 1985 to 2013), although domestic landings did sharply increase to $> 10,000$ t per annum between 2014 and 2016 (Table 2). For the remaining eight species, no significant threats, population collapses or extirpations were uncovered that might diminish their provision to the Canadian market altogether. In fact, several stocks are currently in a stable or favourable condition (Supp. Table S3). Nonetheless, low catch rates for some of these species in the waters of supplier countries may well have limited this provision. For instance, US landings of butter sole (*Isopsetta isolepis*), starry flounder (*Platichthys stellatus*) and sand sole (*Psettichthys melanostictus*) remained very low from their first recordings until the end of the time series (Table 2). All three species are caught in the US West Coast, GoA and BSAI trawl fisheries but, apart from starry flounder, are of little commercial importance (Supp. Table S3). Starry flounder stocks on the US West Coast are not considered overfished or to be undergoing overfishing [52]. Rex sole (*Glyptocephalus zachirus*) is caught in the same three US fisheries, but in considerably higher quantities than the latter three species (Table 2). The GoA and US West Coast stocks of rex sole are above target levels (not overfished, not experiencing overfishing), whereas the status of the BSAI stock is unknown [27]. The rex sole fishery in the GoA has been MSC certified since 2010 [44].

Three species – dab (*Limanda limanda*), lemon sole (*Microstomus kitt*) and brill (*Scophthalmus rhombus*) – appeared in the historical production records of the Netherlands (Table 2), with most of these landings constituting bycatch from North Sea demersal trawl fisheries (Supp. Table S3). Dab is a common and abundant species in the North Sea, and the Netherlands takes by far the greatest proportion of North Sea dab landings [53]. Dutch landings of lemon sole and brill were considerably lower than those of dab over the historical time series (Table 2). However, landings of all three have declined since the turn of the century with decreasing beam-trawl efforts and the introduction of TACs for the species in the North Sea [54]. Despite these declines, the abundance of North Sea dab and lemon sole has fluctuated around stable levels for at least the last two decades, whereas that of North Sea brill has increased (Supp. Table S3). Indian halibut (*Psettodes erumei*) appeared only in the historical production records of Thailand and Indonesia, and the species does not occur in Canadian or US waters [21]. Both former countries contributed marginally towards Canada's flatfish import share (0.006–0.06% for 2007–2016), potentially explaining the absence of Indian halibut in Canadian market surveys (Table 1; Fig. 4).

3.6.6. No apparent basis for CFIA inclusion

Almost a third of the species on the CFIA list ($n = 15$) have never appeared in the historical production records of Canada or any of its prospective flatfish suppliers, nor in Canadian import records or any market surveys over the respective analysis periods (Group H – Fig. 4). Four of these – roughscale sole (*Clidoderma asperrimum*), slender sole (*Lyopsetta exilis*), deepsea sole (*Embassichthys* [*Microstomus*] *bathybius*) and C-O sole (*Pleuronichthys coenosus*) – are native to the Pacific and are found in Canadian and US waters [21], but there is no record of the species on Canada's DFO website (www.dfo-mpo.gc.ca) and no record of any significant commercial catches on the US NOAA fisheries website [27]. Slender sole and C-O sole are of minor commercial significance [21]. Four species – bigmouth flounder (*Hippoglossina stomata*), spotted turbot (*Pleuronichthys ritteri*), hornyhead turbot (*Pleuronichthys verticalis*) and fantail sole (*Xystreurys liolepis*) – are endemic to the Eastern Pacific and occur in US waters but have never been documented in Canadian waters [21]. Additionally, there is no record of the species on the DFO website and no evidence of any commercially significant fisheries or catches in the US (Supp. Table S3). Bigmouth flounder are caught in subsistence fisheries and do not appear to support commercial fisheries, whereas spotted turbot and hornyhead turbot are reportedly of no interest to fisheries [21]. All four species classified as 'tonguesole' on the CFIA list (*Cynoglossus arel*, *C. canariensis*, *C. lingua* and *C. macrolepidotus*) are variably found in the Indo-West Pacific, Western Pacific or Eastern Central Atlantic (Supp. Table S3). A further three species – doublelined tonguesole (*Paraplagusia bilineata*), spottail spiny turbot (*Psettodes belcheri*) and spiny turbot (*Psettodes bennettii*) – are native to the Indo-Pacific or Eastern Atlantic [21]. Nonetheless, none of the latter seven species has ever been recorded in Canadian or US waters [21], nor on Canada's DFO or the US NOAA fisheries websites (Supp. Table S3).

4. Conclusions

Canada's marine fisheries are important contributors to the ecological, socio-economic and cultural fabric of the nation. Yet our findings suggest that the integrity of its domestic seafood supply chain is being eroded by poor organisation and transparency in fisheries data reporting and market labelling. Most of Canada's official flatfish trade statistics, and to some extent its production records, are reported with insufficient specificity to elucidate the precise species involved, to track flatfish trade flows and to inform flatfish exploitation management. Interestingly, in order to import seafood into Canada, the CFIA's 'Fish Import Notification' form requires disclosure of the country of harvest and Taxonomic Serial Number (TSN) of the enclosed species, with the latter linkable to a scientific name in the CFIA fish list [55]. Thus, while species- and origin-specific import records are required and theoretically available, this key information is rarely passed on to subsequent stages of the supply chain or made accessible for public scrutiny [6].

Although seafood naming lists are in place to minimise confusion in fish nomenclature and promote market efficiency, the results of this study cast doubt on whether such lists are achieving their desired goals in Canada. For one, the generic nature of the CFIA-approved common names for flatfishes distorts consumer choice by creating impressions of abundance and concealing the vulnerability status of species marketed under these 'umbrella' terms. Moreover, published data on market samples of flatfish purchased in Canada, including sole samples collected for this study, show a limited number of flatfish species are actually being encountered on the market compared to the dozens of species on the CFIA list. Along with its numerous superfluous species inclusions, the CFIA list's outdated names, missing taxa and poor correspondence with trading partner's naming conventions result in a system inundated by numerous paths of misinterpretation, misclassification and substitution. These shortcomings identified in the CFIA list, and in Canada's seafood labelling regulations in general, are largely inconsistent with the legal tenets of Canadian policy to ensure that fish names have reliable scientific underpinnings, to uphold fair market practices and to not mislead consumers [40]. Furthermore, while our study focused on flatfishes, a similar scenario is likely to extend to many other seafood species marketed in Canada for which such generic and incongruous naming practices remain permissible.

After some delay, Canada has recently ratified the Port State Measures Agreement to combat illegal, unreported and unregulated (IUU) fishing [56], thus it is appropriate and timely that the country proceeds to modernise its seafood labelling and data reporting requirements as part of the shift towards transparency [57]. Several actions are consequently recommended to strengthen seafood labelling and traceability legislative frameworks in Canada and protect the integrity of the domestic seafood supply chain. Firstly, government agencies should improve the reporting of fishery production and trade statistics by necessitating species-level classifications, by verifying that publicly available data are comparable between reporting entities, and by providing these detailed records to official global repositories (e.g. FAO). Secondly, the CFIA fish list undoubtedly requires overhaul and updating to promote more accurate description of realistically available species on the Canadian market. Necessary measures should include resolution of the shortcomings uncovered in this study, as well as the disapproval of vague multispecies 'umbrella' terms and the preferable adoption of a 'one species, one name' approach. Nonetheless, given the ambiguities associated with colloquial names in seafood marketplaces, Canada's labelling legislation should be aligned with that of the EU in mandating scientific names on seafood products, along with additional criteria (geographical origin, processing history, production- and harvest-methods) to promote consumer choice and effective 'boat-to-plate' traceability. Finally, this legislation should be enforced through ongoing regulatory monitoring of labelling authenticity, including DNA barcoding and product trace-backs [57]. Overall, these improvements in taxonomic granularity and accurate information sharing should provide a foundation of enhanced resolution from which to evaluate patterns of domestic species exploitation and tailor sound management and conservation plans.

CRediT authorship contributions statement

DMC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing - original draft, Writing - review & editing. **TEM**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing - review & editing. **AMN**: Project administration, Supervision, Writing - review & editing. **RHH**: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision.

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Declaration of interests

None.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2020.104335.

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