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Energy direct inputs and greenhouse gas emissions of the main industrial trawl fishery of Brazil

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ABSTRACT

This study provides first-time estimates of direct fuel inputs and greenhouse gas emissions produced by the trawl fishing fleet operating off southeastern and southern Brazil. Analyzed data comprised vessel characteristics, landings, fishing areas and trawling duration of [illegible],144 fishing operations monitored in Santa Catarina State from 2003 to 2011. Three main fishing strategies were differentiated: 'shrimp trawling', 'slope trawling' and 'pair trawling'. Jointly these operations burned over 9.1 million liters of diesel to land 342.3 million kilograms of fish and shellfish. Annually, 0.023–0.031 l were consumed for every kg of catch landed. Because all fishing strategies relied on multispecific catches to raise total incomes, estimates of fuel use intensity were generally low but increased 200–900% if only nominal targets were considered. In nine years trawling operations emitted 6.69 GgC to the atmosphere, between 2300 and 3300 tons CO_2 per year.

RETRACTED

1. Introduction

Industrial fishing is responsible for the bulk of annual world catches, providing an important fraction of global increasing demands for seafood products (FAO, 2012). Such benefits, nonetheless, are counterbalanced by an array of potential or effective environmental costs/impacts, most notably: (a) reduction of wild stocks biomass through overfishing (Garcia and Grainger, 2005), (b) alteration of community structure and ecosystem functioning through reduction of top-predators, bycatch and discards (Pauly et al., 1998, 2005; Kelleher, 2008), (c) degradation of habitats through contact of fishing equipment with the seafloor (Kaiser et al., 2006), (d) consumption of fossil fuels during navigation and fishing operations (Tyedmers, 2004; Tyedmers et al., 2005; Suuronen et al., 2012), (e) emission of green-house gases to the atmosphere (Ziegler and Hansson, 2003; Fulton, 2010). For decades assessment of fishing sustainability have focused on overfishing and more recently on marine ecosystem impacts (a, b and c). Less consideration has been given to the fact that these impacts have been powered by the availability and consumption of fossil fuels (Tyedmers, 2004; Tyedmers and Parker, 2012), which in turn produce additional environmental harm through CO_2 emissions to the atmosphere contributing to global environmental changes.

Tyedmers et al. (2005) estimated that fishing activity burned 1.2% (50 billion tons) of all oil consumed in the planet in 2000. This was the fuel cost of nearly 80 million tons of landed fish and shellfish and the source of 130 million tons of CO_2 released to the atmosphere. Because the energy made available to human assimilation through the consumption of this amount of seafood was approximately 1/12 of the energy dissipated to conduct fishing, these authors concluded that the efficiency of the fishing activity is generally low. However, such efficiency is not homogeneous as the various methods currently employed to capture valuable benthic, demersal and pelagic stocks may demand different levels of "energy inputs" and consequently vary in their "energy performance" (*sensu* Tyedmers, 2004). In general, 'passive' fishing methods (e.g. gillnets, traps, longlines) tend to be less energy demanding that 'active' ones (e.g. trawls and seines) (Tyedmers et al., 2005; FAO, 2007; Schau et al., 2009; Winther et al., 2009).

Bottom trawling constitutes worldwide the main source of demersal and benthic fish and shellfish products (Thurstan et al., 2010). Nonetheless, bottom trawl fisheries are often regarded as unsustainable from an environmental perspective mainly because bottom trawls nets (a) are generally little selective, producing an abundant and diverse bycatch and discards (Kelleher, 2008), and (b) often disturb seafloor habitats and benthic communities due to contact of heavy gear (e.g. otter doors, ground ropes) (Auster and Langton, 1999; Hiddink et al., 2006). Additionally, the energetic efficiency of trawlers is often poor as a result of variable stock

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catchability patterns (aggregation and proximity of fishing grounds) and the significant drag force produced by otter trawls during fishing operations, which demand a large amount of engine power and fuel consumption (Wileman, 1984; Tyedmers, 2004). Temporal variation in these elements, e.g. decreases in relative abundance and increases in size and power of fishing vessels, contribute to changes on the energy performance over time, as reported for various trawl fisheries worldwide (Tyedmers, 2004).

In southeastern and southern Brazil (SW Atlantic, 19° – 34°S), bottom trawlers have historically produced the main fraction of demersal catches. By the end of the 1990s and throughout the 2000s the trawl fleet included over 650 vessels whose joint annual landings oscillated around 89 thousand tons, approximately 1/3 of all fish and shellfish biomass landed in the region (Perez et al., 2001; Valentini and Pezzuto, 2006). Stock assessments produced throughout this period have concluded that the main target stocks, harvested both in the shelf and the slope areas, have undergone biomass reductions reaching, or even surpassing, maximum sustainable levels (Haimovici, 1997; D'Incao et al., 2002; Haimovici et al., 2006; Perez et al., 2009). Generally attributed to overfishing, this scenario has become an evidence of a direct impact of the trawl fisheries on the benthic ecosystems of southeastern and southern Brazil. Other sources of ecosystem impacts including, *inter alia*, habitat disturbance, change of community structure, fossil fuel consumption and greenhouse gas emissions, however, have been poorly studied (e.g. Gasalla and Rossi-Wongtschowski, 2004; Almeida and Vivan, 2011) or are virtually unknown.

Coastal areas of the SW Atlantic were shown to contribute little to Tyedmers et al. (2005) global assessment of marine fisheries fuel consumption and greenhouse gas emissions in 2002. These [illegible], however, lacked empirical data and were mostly assessed through the adoption of surrogates from similar fisheries elsewhere. This study provides first-time estimates of direct fuel inputs and CO_2 emissions produced during nine years by the trawl fishing fleet operating off southeastern and southern Brazil. Fuel use intensity and carbon balance of trawling operations and their main temporal and spatial patterns were further analyzed to assess the environmental costs of this anthropic activity and its impacts over the Brazilian continental margin. Overall it intends to contribute to a broader assessment of costs and benefits of this large-scale seafood production in Brazil.

2. Material and methods

2.1. Bottom trawl fisheries

Bottom trawling in southeastern and southern Brazil developed in the 1960's essentially as a coastal shrimp (*Farfantepenaeus paulensis*, *F. brasiliensis* and *Xyphopenaeus kroyeri*) fishery. During the following 40 [illegible] shrimp stocks decreased, the activity expanded over the continental shelf and diversified its targets, including groundfish of the family Sciaenidae (i.e. *Micropogonias furnieri*, *Cynoscion guatucupa*, *Macrodon ancylodon*, *Umbrina canosai* and others) and flatfish (*Paralychthys* spp.) as well as valuable shellfish species (i.e. shrimps *Artemesia longinaris* and *Pleoticus muelleri*, lobsters *Metanephrops rubellus* and *Scillarides depressus* and cephalopods *Doryteuthis plei* and *Octopus vulgaris*). In the last decade, trawling operations expanded to the slope areas (down to 800 m depths) and initiated an unprecedented exploration of deep water resources such as monkfish (*Lophius gastrophysus*), Argentine hake (*Merluccius hubbsi*), Brazilian codling (*Urophycis mystacea*), Argentine squid (*Illex argentinus*) and deep water shrimps (Family Aristeidae) (Perez et al., 2001, 2009).

At the present time over 650 trawlers operate from Espírito Santo state (19°S) to the southern border of Brazilian EEZ (34°S) establishing a footprint that extends from littoral waters (~10 m depth) to the slope (~800 m depth). The fleet comprises double rig (75%), pair (23%) and stern (2%) trawlers that exhibit distinct operation patterns based on spatial and temporal availability of demersal resources and their gear fishing capabilities. These patterns have been used to characterize three main 'fishing strategies' used in this study:

- *Shrimp trawlers (ST):* mostly double-rig trawlers that tend to operate on inner – middle shelf concentrating in two distinct fishing grounds; one between 24° and 29°S directed mainly at pink (*Farfantepenaeus* spp.) and [illegible] shrimps (*X. kroyeri*) concentrations and a second, south of [illegible]°S directed at other coastal shrimps (*A. longinaris* and *P. muelleri*) and a group of demersal finfish that include *U. canosai*, the searobin (*Prionotus punctatus*) and flatfish (*Paralychthys* spp.). These species make up over 60% of the total biomass landed by shrimp trawlers in 2003–11.
- *Slope trawlers (SLT):* double-rig and stern trawlers that operate on the slope areas (250–[illegible] m depths) aiming principally at Brazilian codling, Argentine hake and monkfish. These species and also *U. canosai* and *P. punctatus* comprise over 64% of the biomass landed by slope trawlers between 2003 and 2011.
- *Pair trawlers (PT):* in this strategy two vessels trawl in large net. These trawlers operate on the inner shelf aiming at a few sciaenid fish species, including *U. canosai*, *M. furnieri*, *C. guatucupa*, *C. acoupa* and *C. jamaicensis*, which comprised altogether approximately 78% of total landings between 2003 and 2011.

2.2. Data sources

The analyzed data set comprised information on catch, effort and fishing areas of 10,144 fishing trips (double rig trawlers = 8012 trips; Stern trawlers = 949 trips; Pair trawlers = 1183 trips) that landed their catch in the harbors of Santa Catarina state between 2003 and 2011. Data were reported by skippers in log books or during interviews at the time of the landings, following a routine sampling protocol established by Santa Catarina State industrial fishing statistical service (Perez et al., 1998; www. univali.br/gep). The information reported by these two instruments were criticized by experienced analysts as part of this routine protocol, based on long term trends of the trawl fishery (e.g. fishing areas, depths, common species in the catch, catch values, trip duration etc.). Each report was categorized as "reliable", "dubious" or "unreliable" and only those in the former category were included in the analyzed database. Because "dubious" reports were generally uncharacteristic but did not necessarily contain spurious information, they underwent a second evaluation and were eventually "rescued" from the rejected report pool. This was the particular case when more than one instrument (logbook and interview) was available for the same individual landing and these could be crosschecked for consistency.

Analyzed landing reports represented a known fraction (approximately 70%) of total landings in Santa Catarina state (UNIVALI/CTTMar, 2004, 2006, 2007a, 2007b, 2008, 2009, 2010, 2011, 2013). Therefore the transformed variables (e.g. fishing trips, fuel consumption, carbon emissions, see below) were upscaled to the entire trawl fishing activity recorded in Santa Catarina (Table 1). No attempts were made to upscale these figures to the all southeastern and southern Brazil. This would require full records of landings in other states (mainly São Paulo, Rio de Janeiro and Rio Grande do Sul) that are unavailable or incomparable to those collected in Santa Catarina. But it is assumed these are highly representative of the entire region since the state harbors nearly 60% of the entire fleet and records annually 50–70% of trawl fishing landings (Perez et al., 2001). Additionally the volume of discarded catch has not been included in the analysis due to lack of informa-