ORIGINAL RESEARCH

Greenhouse gas emissions, consumption and fuel use intensity by an artisanal double-rig trawl fleet in southern Brazil

Dagoberto Port[1], Fernando Niemeyer Fiedler[2, *], Fabiane Fisch[1] and Joaquim Olinto Branco[1]

[1]School of the Sea, Science and Technology, Universidade do Vale do Itajaí (Univali), Brazil. [2]Centro Nacional de Pesquisa e Conservação da Biodiversidade Marinha do Sudeste e Sul (CEPSUL), Avenida Carlos Ely Castro 195, Cep 88301-445 - Itajaí, Brazil.
ORCID *Dagoberto Port* http://orcid.org/0000-0003-3909-7957, *Fernando Niemeyer Fiedler* https://orcid.org/0000-0001-5706-1937, *Fabiane Fisch* http://orcid.org/0000-0002-9011-7020, *Joaquim Olinto Branco* http://orcid.org/0000-0002-3521-1671

ABSTRACT. In Brazil, most national marine production is captured by artisanal fisheries. The present study was conducted in a traditional trawl fishing area for the capture of the Atlantic seabob shrimp Xiphopenaeus kroyeri in southern Brazil between 1996 and 2015 to obtain initial estimates of direct fuel inputs and greenhouse gas emissions. Data include vessel characteristics, total and seabob shrimp production, and trawl duration. Approximately, four million liters of fuel were consumed for an estimated catch of around 148,000 kg of fish (26.4 l kg^{-1}), of which 19,000 kg were seabob shrimp (206 l kg^{-1}) or 13% of total production. The carbon emitted by this fleet was almost three million gigagrams (GgC), between 401 and 666 t per year. Although the number of vessels has increased over the years, catches, especially of seabob shrimp, have declined sharply, indicating over-exploitation of this resource and reinforcing the urgent need to create management programs and selective technologies for this modality.

Key words: Artisanal trawl fishery, shrimp, energy efficiency, greenhouse gases, fuel use intensity, carbon balance.

Emisiones de gases de efecto invernadero, consumo e intensidad de uso de combustibles por una flota de arrastre artesanal de doble aparejo en el sur de Brasil

RESUMEN. En Brasil, la mayor parte de la producción marina nacional es capturada por la pesca artesanal. El presente estudio se realizó en un área de pesca de arrastre tradicional para la captura del camarón siete barbas del Atlántico Xiphopenaeus kroyeri en el sur de Brasil entre 1996 y 2015 para obtener estimaciones iniciales de las entradas directas de combustible y las emisiones de gases de efecto invernadero. Los datos incluyen las características de las embarcaciones, la producción total y de camarones siete barbas y la duración de los arrastres. Se consumieron aproximadamente cuatro millones de litros de combustible para una captura estimada de alrededor de 148.000 kg de pescado (26,4 l kg^{-1} capturados), de los cuales 19.000 kg fueron camarones siete barbas (206 l kg^{-1} capturados) o el 13% de la producción total. El carbono emitido por esta flota fue de casi tres millones de gigagramos (GgC), entre 401 y 666 t anuales. Si bien el número de embarcaciones ha aumentado a lo largo de los años, las capturas, especialmente de camarón siete barbas, han disminuido drásticamente, lo que indica una sobreexplotación de este recurso y refuerza la necesidad urgente de crear programas de manejo y tecnologías selectivas para esta modalidad.

Palabras clave: Pesca artesanal de arrastre, camarón, eficiencia energética, gases de efecto invernadero, intensidad de uso de combustibles, balance de carbono.

*Correspondence: fnfiedler@hotmail.com

Received: 10 February 2022
Accepted: 22 March 2022

ISSN 2683-7595 (print)
ISSN 2683-7951 (online)

https://ojs.inidep.edu.ar

Journal of the Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP)

INTRODUCTION

According to estimates, approximately 60 million people are involved in fishing and aquaculture and around 65% depend directly on fishing for their livelihood (FAO 2020). The capture, processing, and sale of fish from artisanal fisheries play a key role in providing food to the world's population (Salas et al. 2018). In Brazil, around one million people are directly involved in fishing. Specifically, artisanal fishing historically accounts for a large part of national marine production, thus reinforcing the economic and social importance of this modality (Abdallah and Bacha 1999; Zamboni 2020). However, information related to the fishery tends to be unreliable and fishers rarely participate in its management, which causes a series of problems such as their gradual loss of political and economic representativeness (Salas et al. 2007; Medeiros et al. 2014; Dias Neto and Oliveira Dias 2015; Oliveira Leis et al. 2018).

Since this fishery involves a wide variety of environments and species, its impacts are a growing cause for concern, especially in terms of stock reduction (Garcia and Grainger 2005), changes in ecosystem structure and functioning (Pauly et al. 1998, 2005; Kelleher 2008), changes in the ocean floor (Kaiser et al. 2006; Kaiser 2019), mortality of endangered species (Sales et al. 2010; Fiedler et al. 2012, 2017, 2020), consumption of fossil fuels in navigation and fishing operations (Tyedmers 2004; Tyedmers et al. 2005; Suuronen et al. 2012), and greenhouse gas emissions (Ziegler and Hansson 2003; Fulton 2010; Port et al. 2016). In the last two decades alone, the impact of the two latter factors has served to assess the sustainability of fishing (Tyedmers 2004; Tyedmers and Parker 2012; Jha and Edwin 2019), especially large-scale fisheries in developed countries given the scarcity of data on small-scale or artisanal fisheries in developing countries (Parker et al. 2018).

For 2000, Tyedmers et al. (2005) estimated that fisheries landed approximately 80 million tons of fish, consumed 50 billion liters of oil, which is 1.2% of all oil used worldwide, and released around 130 million tons of CO_2 into the atmosphere. According to Parker et al. (2018), however, fisheries consumed an estimated 40 billion liters and emitted 179 million tons of CO_2. Because the energy for human assimilation by the consumption of this total captured is 1/12 of the energy required for the capture, the efficiency of this activity is generally low. Notably, however, different fishing modalities have different energy performances, that is, they require different levels of fuel consumption for their catch efficiency (Tyedmers 2004; Crowder et al. 2008). In this regard, passive methods (e.g. longline, trap, and gillnet) tend to require less energy than active methods (e.g. trawl, seine net) (Tyedmers et al. 2005; FAO 2007; Schau et al. 2009; Winther et al. 2009).

Demersal and benthic species for consumption are captured worldwide by trawl fisheries (Thurstan et al. 2010). Among other factors, the energy efficiency of this modality is generally deficient mainly due to variable capture patterns, large engine power, and high fuel consumption (Wileman 1984; Tyedmers 2004).

In the state of Santa Catarina, southern Brazil, approximately 20 thousand people in 36 coastal municipalities are directly involved in artisanal fishing (PCSPA-SC 2015). In these municipalities, artisanal fishing accounted for 43% of the total landing volume in the state between 2017 and 2019 (PMAP/SC 2020). Moreover, the municipality of Penha is the fifth largest artisanal producer in the state. The fleet of Penha mostly consists of open vessels with an inboard engine and without pilothouse. The most widely used fishing gear are gillnets (fixed and drift net) and double-trawl nets, mainly used to catch codling *Urophycis* spp., anchovy *Pomatomus saltatrix* (Linnaeus, 1766), catfish *Genidens* spp., croaker *Micropogonias furnieri* (Desmarest, 1823), weakfish *Cynoscion* spp., mullet *Mugil liza*

(Valenciennes, 1836), and shrimp (PMAP/SC 2020). Of the shrimp, the most frequently captured species is the Atlantic seabob *Xiphopenaeus kroyeri* (Heller, 1862) with an estimated 177.3 t year^{-1} (Branco and Verani 2006).

Although artisanal fishing in the municipality has been widely studied (Almeida and Branco 2002; Bail and Branco 2003, 2007; Branco and Fracasso 2004; Branco 2005; Branco and Verani 2006; Branco et al. 2013; Coelho et al. 2016; Acauan et al. 2018a, 2018b; Barrili et al. 2021), little is known about the energy efficiency of shrimp trawling and its real impacts on the marine environment. The present study evaluated for the first time the relationship between fuel consumption and total catches of artisanal trawl fishing, between 1996 and 2015 in a community of Armação do Itapocoroy, municipality of Penha, north-central coast of Santa Catarina, Brazil, to support ecosystem management for this activity.

MATERIALS AND METHODS

Study area

The study area is located in the municipality of Penha (26° 46′ S-48° 38′ W), north-central coast of the state of Santa Catarina, Brazil (Figure 1). Penha has an estimated population of 30,262 inhabitants and its main activities are tourism, mariculture, and fishing (Branco 2005; IBGE 2017).

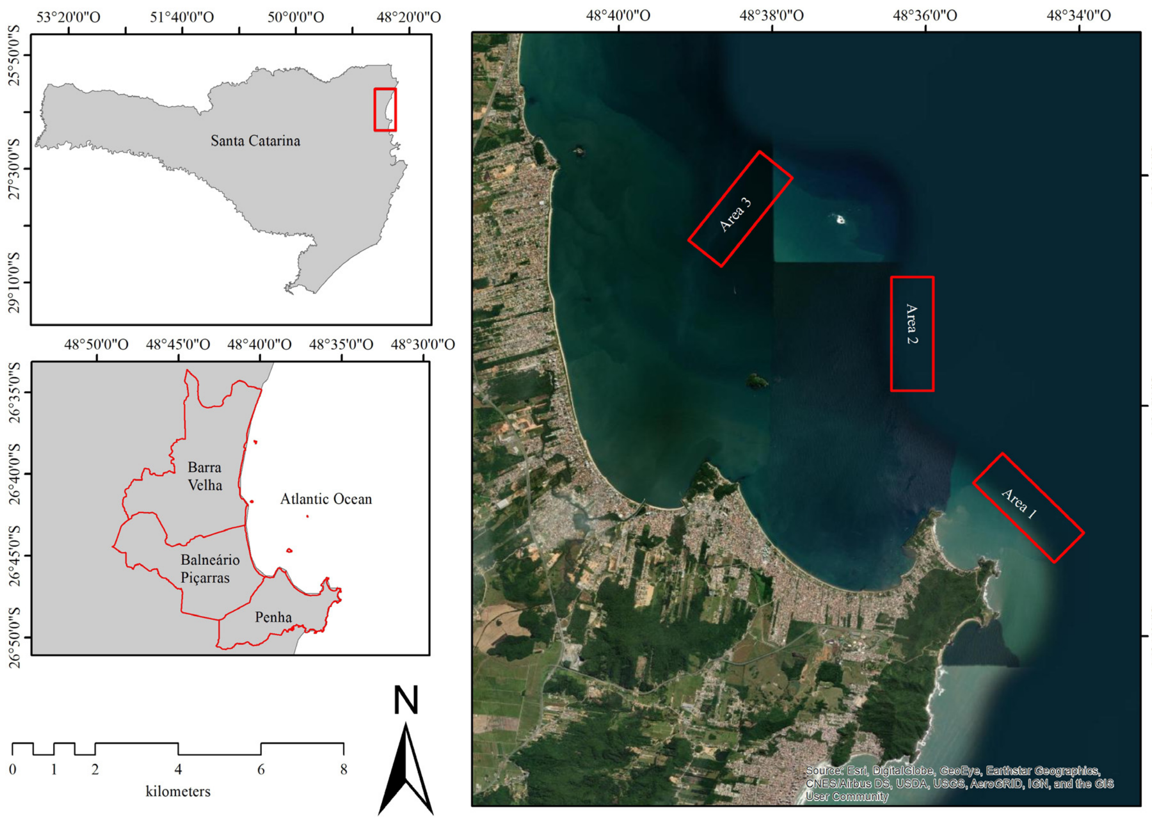

Figure 1. Location of the municipality of Penha - SC, Brazil, and the three main fishing areas of the seabob shrimp *Xiphopenaeus kroyeri* by the artisanal trawl fleet of the community of Armação do Itapocoroy.

Artisanal trawl fishing

In Armação do Itapocoroy beach, 115 artisanal vessels navigate an area of approximately 168 km^2 and mainly target the Atlantic seabob shrimp *Xiphopenaeus kroyeri* (Acauan et al. 2018a). In the present study, trawls were carried out monthly between 1996 and 2015, in the three fishing areas traditionally used by the local fishing community (Figure 1).

The same methodology was used throughout the study period. Moreover, the same double-rig trawler was used and leased from a local fisher, who also drove the vessel in all the trawls.

Two identical nets were used, with 3.0 cm mesh on the wings and 2.0 cm on the body and cod end. The speed of all the trawls was 2.0 knots. For each sampling, three trawls were performed for one hour each.

Every catch was selected by the fisher on the deck of the vessel based on their knowledge and daily practice. Species were classified into the following two initial categories: a) nominal catch, which refers to the set of species retained for sale, mainly the seabob shrimp; and b) discarded catch, which are the species returned to the sea because they are not sold or because they are sold but their size is below the minimum allowed size for sale. The nominal catch was separated into the following two categories: a) target species, that is, those that have economic importance; and b) incidental species, which are not feasible for fisheries but can be used for consumption and/or sold in the local market. The total sample catch (nominal catch + discarded catch) was separated in clearly identified refrigerated boxes. At the laboratory, these samples were selected, and the specimens were subsequently counted, weighed, subjected to biometric recognition, and identified to the lowest possible taxonomic level using specialized literature (Menezes et al. 2003; and references contained therein).

The information was entered into an excel spread-sheet after cross-validation, whereby one researcher reviews the information entered by another.

Fishery activity information

Since socio-economic data of the trawler fleet in the municipality were not systematically collected, engine power (Hp) data were initially obtained through a literature review of publications in scientific journals, unpublished data, and gray literature (theses and dissertations). Subsequently, detailed information collected by the Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina –EPAGRI (Company of Agriculture, Research, and Rural Extension of Santa Catarina) for 2011 (Everton Della Giustina and Daniela M. G. Nunes, unpublished data) revealed the low variation in engine power values over the years. Thus, an extrapolation was carried out proportionally for the other years, considering the total number of vessels operating each year (Table 1).

Data transformation

Total fuel consumption during fishing operations was estimated through the relationship between total trawling hours and total vessel engine power (Brazil 2011) using the following formula:

$$FC_{ei} = TH_{ei} \times FHP \times HP_e$$

where FC_{ei} is the amount of oil, in liters, consumed by the e^{-eth} trawl during the i^{-eth} fishing trip; TH_{ei} is the time, in hours, the e^{-eth} vessel spent trawling during the i^{-eth} trip; FHP is the amount of oil, in liters, consumed per hour and per vessel engine horsepower (standard value at 0.0963 l/Hp); and HP_e is the power of the e^{-eth} engine expressed in Hp.

The intensity of fuel use for each fishing trip FUI_i was expressed by the following formula:

Table 1. Source of engine power (Hp) data available for each year for the artisanal fleet of double-rig trawlers of Armação do Itapocoroy, municipality of Penha - SC, Brazil. Data from 2011 (EPAGRI, unpublished data) used for extrapolation and calculations of fuel consumption and intensity of use and carbon emission. -: period without information.

	Engine power (Hp)		
Year	Min	Max	Source
1996	15	45	Branco (2001), Branco and Fracasso (2004)
1997	15	45	Branco (2001), Branco and Fracasso (2004)
1998	16	40	Fracasso (2002), Branco and Fracasso (2004)
1999	16	40	Fracasso (2002), Branco and Fracasso (2004), Campos (2004)
2000	16	40	Fracasso (2002), Branco and Fracasso (2004), Campos (2004)
2001	16	40	Fracasso (2002), Branco and Fracasso (2004), Campos (2004)
2002	16	40	Branco and Fracasso (2004), Bail and Branco (2007)
2003	10	24	Bail and Branco (2007)
2004	-	-	-
2005	-	-	-
2006	-	-	-
2007	-	-	-
2008	-	-	-
2009	-	-	-
2010	10	36	Santos (2011)
2011	10	60	EPAGRI (2011), Santos (2011)
2012	-	-	-
2013	-	-	-
2014	17,44	24,25	PCSPA/UNIVALI (2015)
2015	17,44	24,25	PCSPA/UNIVALI (2015)

$$FUI_i = FC_{ei}/LC_i$$

where LC_i is the nominal catch of the i^{-eth} trip, in kg.

For the present study, the 'carbon balance' was considered as the ratio between the amount of carbon removed from the marine environment *vs* the carbon emitted into the atmosphere from the consumption of diesel oil during fishing operations. Therefore, total catch and seabob shrimp catch separately for each trip (kg) were transformed into carbon units (C_i) using the following equation:

$$C_i = (LC_i \times CR) / 1{,}000{,}000$$

where CR refers to the biomass/carbon conversion rate, considered 9:1 (Pauly and Christensen 1995; Ziegler 2006; Ziegler and Valentinsson 2008; Fulton 2010; Port 2015; Port et al. 2016).

The fuel consumed on each fishing trip was converted into 'standard energy units', defined as tEP, by which 1 toe = 45.2×10^{-3} TJ (TJ = 1,012 J) (Brasil 1999). The following equation described by Álvares Júnior and Linke (2002), Macêdo (2004) and Pinto and Santos (2004) was used:

$$EC_{ei} = FC_{ei} \times Fconv \times 45.2 \times 10^{-3} \times Fcorr$$

where EC_{ei} is the energy dissipated by the e^{-eth} vessel during the i^{-eth} fishing trip, expressed in TJ; Fconv is the factor used to convert a certain amount of fuel into tEP, considering the 'high heat value' (HHV) of the fuel, surveyed annually by the National Energy Balance of the Brazilian Ministry of Mines and Energy (EPE 2011). The value used of nautical diesel oil for 2010 was determined, namely 0.848 tEP m^{-3}. In contrast, Fcorr is the factor used to correct Fconv from HHV to "low heat value" (LHV). This conversion was required to ensure energy contents estimated by the National Energy Balance were comparable to those recommended by the Intergovernmental Panel on Climate Change (IPCC). Fcorr for solid and liquid fuels was set at 0.95 (Brazil, 2006). The amount of carbon emitted by oil consumption during the fishing trip was calculated using the following equation described by Álvares Júnior and Linke (2002), Macêdo (2004), and Pinto and Santos (2004):

$$CE_{ei} = EC_{ei} \times Femiss \times 10^{-3}$$

where CE_{ei} refers to the carbon, expressed in Gigagrams (GgC = 1,000 t carbon), emitted by the e^{-eth} vessel during an i^{-eth} fishing trip; Femiss is the carbon emission factor, expressed in ton of carbon (tC), per TJ. For diesel oil, this value corresponds to 20.2 tC/TJ (IPCC 1996; Brasil 2006). The 10^{-3} multiplication was performed to express the value in GgC. The carbon balance for each fishing trip was expressed as a ratio CE_{ei}/C_i.

Finally, GgC values were converted to tons of carbon dioxide (CO_2), using the following equation described by Macêdo (2004):

$$ECO_2 = (CE_{ei} \times 44/12) \times 1,000$$

Data analysis

Since the main purpose of this study was to obtain the aggregate estimates of fuel consumption and intensity of use, carbon emissions, and carbon energy balance for trawl fisheries in Itapocoroy, the transformed variables were grouped by year and for the entire study period.

RESULTS

During the study period (1996-2015), an annual average of 78 vessels were operating in the shrimp trawl fishery, with a minimum of 59 (2001) and a maximum of 96 (2015). The average power of vessel engines was 21 Hp (min = 10; max = 60 Hp). They operated 240 each year, with six trawls a day of one hour each. From 2004, the number of shrimp trawlers gradually increased (Figure 2).

Regarding biomass, the total catch estimate for the study period was 148,082 kg of fish (min = 2,906.5 kg in 2009; max = 12,528.2 kg in 1999). For the seabob shrimp, the total catch estimate was 19,002 kg (min = 45 kg in 2015; max = 3,418.2 kg in 2010), representing an average of 12.8% of the total catch (min = 1.0% in 2014; max = 35.5% in 2010) (Table 2). Although the number of vessels gradually increased from 2004, total and seabob shrimp catches did not increase (Figure 2).

Total catches peaked in 1999 (12,528.21 kg), followed by a gradual decline until 2009 (2,906.47 kg). Subsequently, in 2010 catches recovered with 9,626.72 kg landed, followed by another drop in catches. In contrast, seabob shrimp catches remained relatively stable from 1998, reaching a maximum in 2010 (3,418.18 kg), followed by a sharp decline, until reaching a negligible 44.97 kg in 2015 (Figure 2).

The approximate total fuel consumption was 3,909,000 l (min = 149,000 l in 2001; max = 247,000 l in 2015). As for intensity of fuel use, approximately 3,909,000 l of fuel (average = 26.4 l kg^{-1} catch) was used for the estimated total of 148,082 kg fish landed (Table 2). Considering

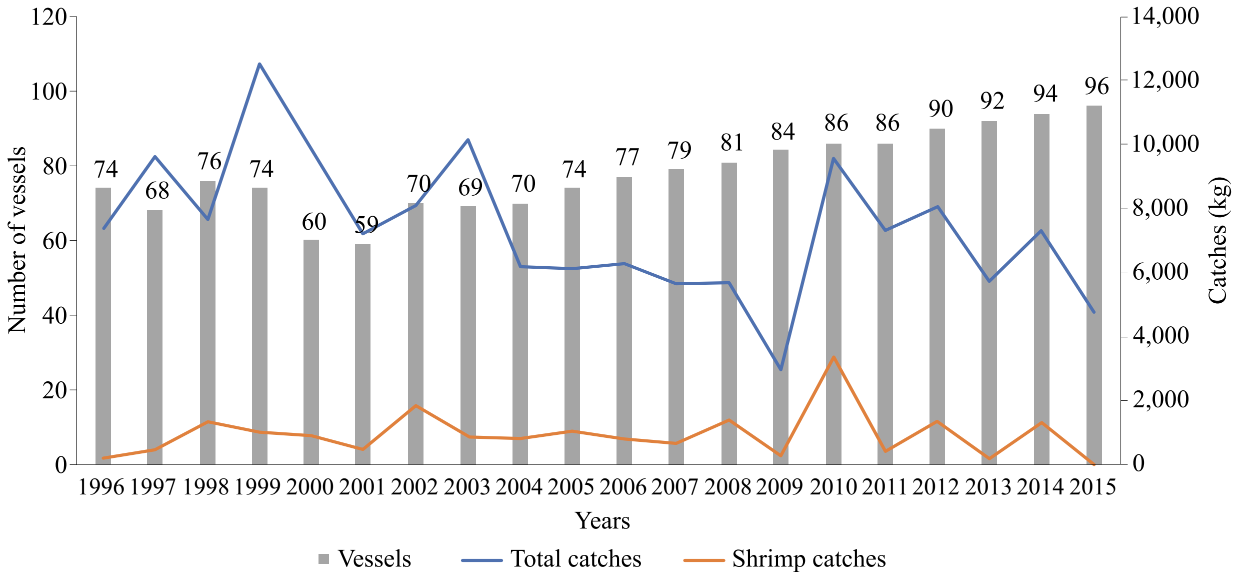

Figure 2. Number of vessels, total catch, and seabob shrimp *Xiphopenaeus kroyeri* catches by the artisanal trawl fleet of the community of Armação do Itapocoroy, municipality of Penha - SC, Brazil, from 1996 to 2015.

only the seabob shrimp, around 19,002 kg were landed with this same amount of fuel, averaging 206 l consumed for each kg of shrimp caught.

Regarding the amount of carbon emitted by this fleet over the years, the total was 2,875.22 GgC (min = 109.4 in 2001; max = 181.7 in 2015) (Table 2). For the carbon balance, the estimated total capture was 174,747.54 GgC (min = 95,883.68 in 1999; max = 476,445.3 in 2009). For the seabob shrimp alone, the total was 1,361,805.43 GgC (min = 419,763.45 in 2010; max = 36,354,339.35 in 2015) (Table 2). Finally, estimated total CO_2 emissions was 10,542.46 t, with a minimum of 401.03 t for 2001 and a maximum of 666.13 t for 2015 (Table 2).

DISCUSSION

Although fisheries play an important role in supplying animal protein to the world's population, the relationship between total expenditure and income obtained during a fishing trip is often negative in some modalities. Moreover, accurate information on these operations required assessing negative impacts on the ecosystem beyond target species and bycatch, e.g. is not readily available for all fishing activities. In this regard, Branco and Fracasso (2004) identified 28 different species of crustaceans in the seabob shrimp fishery, mostly comprising immature individuals, which causes a negative impact on the benthic ecosystem and, consequently, on the activity as a whole.

Moreover, socioeconomic data is often collected for specific periods and, in most cases, only to characterize the fishing activity in particular, even in long-term projects. The data collected with such a specific methodology fails to reflect the actual, real-life events of fisheries, which involve high dynamism due to the constant inclusion of new equipment (including engines) and/or ways of operation. Since socioeconomic data, such as number of operating vessels, were not collected annually for the present study, calculations were based on the best available data set for the other years, provided by EPAGRI.

Table 2. Information for each year (1996-2015) of number of operating vessels; estimated total nominal catch (Lci) and seabob shrimp *Xiphopenaeus kroyeri* catches, percentage (%) of seabob shrimp in relation to total catch; total fuel consumption (FCei); estimated fuel use intensity (FUIi), total and for seabob shrimp; carbon emitted by fuel consumption, estimated carbon balance (BC) for total catch and seabob shrimp catches; and CO_2 emission (ECO_2); for the artisanal double-rig trawl fleet of Armação do Itapocoroy, municipality of Penha - SC, Brazil.

		Lci (kg)				FUIi (l kg^{-1})			BC (GgC)		
Year	Vessel (n)	Total	Shrimp	Shrimp %	FCei (l)	Total	Shrimp	CEei (GgC)	Total	Shrimp	ECO_2 (t)
1996	74	7,321.40	236.6	3.23	181,460.37	24.78	766.95	133.47	164,073.88	5,077,136.43	489.40
1997	68	9,640.38	452.04	4.69	166,338.68	17.25	367.97	122.35	114,222.27	2,435,926.12	448.62
1998	76	7,675.32	1,347.74	17.56	186,500.94	24.30	138.38	137.18	160,855.60	916,067.18	502.99
1999	74	12,528.21	1,044.34	8.34	181,460.37	14.48	173.76	133.47	95,883.68	1,150,248.90	489.40
2000	60	9,842.03	898.77	9.13	153,737.26	15.62	171.05	113.08	103,406.10	1,132,350.04	414.63
2001	59	7,193.36	492.26	6.84	148,696.70	20.67	302.07	109.37	136,842.63	1,999,676.66	401.03
2002	70	8,093.64	1,834.03	22.66	176,419.81	21.80	96.19	129.76	144,296.23	636,784.86	475.80
2003	69	10,191.12	871.43	8.55	171,379.24	16.82	196.66	126.06	111,323.80	1,301,898.00	462.21
2004	70	6,144.41	818.69	13.32	176,419.81	28.71	215.49	129.76	190,072.31	1,426,528.94	475.80
2005	74	6,129.60	1,058.73	17.27	183,980.66	30.02	173.78	135.33	198,697.37	1,150,377.45	496.20
2006	77	6,270.83	820.94	13.09	189,021.22	30.14	230.25	139.03	199,543.38	1,524,229.80	509.79
2007	79	5,665.91	678.38	11.97	196,582.07	34.70	289.78	144.59	229,681.45	1,918,323.63	530.18
2008	81	5,706.77	1,411.62	24.74	201,622.64	35.33	142.83	148.30	233,884.08	945,522.32	543.78
2009	84	2,906.47	248.34	8.54	209,183.49	71.97	842.34	153.86	476,445.28	5,576,232.68	564.17
2010	86	9,626.72	3,418.18	35.51	216,744.34	22.51	63.41	159.43	149,046.28	419,763.45	584.56
2011	86	7,310.72	436.62	5.97	216,744.34	29.65	496.42	159.43	196,263.39	3,286,223.50	584.56
2012	90	8,061.67	1,367.58	16.96	229,345.75	28.45	167.70	168.69	188,329.17	1,110,168.34	618.55
2013	92	5,698.67	160.89	2.82	234,386.32	41.13	1,456.82	172.40	272,276.88	9,644,022.46	632.14
2014	94	7,348.71	1,359.78	18.50	241,947.17	32.92	177.93	177.96	217,952.22	1,177,888.99	652.53
2015	96	4,725.90	44.97	0.95	246,987.73	52.26	5,491.67	181.67	345,973.13	36,354,339.35	666.13
Total		148,081.84	19,001.93	12.83	3,908,958.90	26.40	205.71	2,875.22	-	-	10,542.46

In general, only a slight variation in the total number of vessels operating in Armação do Itapocoroy was observed between 1996 and 2004. This number increased from 2004, probably due to government incentives for fishing fleets. More vessels, however, did not lead to an increase in total catches and seabob shrimp catches annually, as the largest catch occurred in 1999 (12,528.21 t of fish) with 74 trawlers. After 2004, when the number of vessels increased gradually, total catches did not exceed 9,626.72 t (2010), with an effort of 86 vessels. Port (2015) observed a similar trend for the industrial trawl fleet that lands in Santa Catarina, Brazil, and reported an increase in seabob shrimp landings from 2003 and a peak in landings in 2010, followed by a trend of declining catches which may be related to the over-exploitation of resources.

According to Tyedmers (2004), temporal variations in some elements, such as decreasing relative abundance of stocks and increasing size and power of vessel engines, directly contribute to changes in energy performance over time. In terms of industrial fishing, evidence shows that the impact of trawling on benthic ecosystems in southeastern and southern Brazil is directly related to overfishing, that is, catches above the maximum sustainable levels (Haimovici et al. 2006; Perez et al. 2009). According to Ostrom et al. (2007), however, over-exploitation and misuse of ecological systems are rarely attributed to a single cause and the use of simplistic and generalist solutions often increases problems rather than solve them. For Grafton et al. (2008) and Squires (2009), major challenges to this issue go beyond overfishing and include environmental, ecological, and biodiversity factors. In this respect, fisheries must consider management from the ecosystem standpoint since fishing affects trophic levels that are unrelated to the commonly targeted species (Pauly et al. 1998), such as those considered vulnerable, with low reproductive success rate, slow growth, and long-life cycle (Hall et al. 2000).

Results presented here were obtained from estimated total consumption and intensity of fuel use, amount of carbon emitted, carbon balance, and CO_2 emission. However, the calculated values may have been underestimated, given the difficulty in obtaining accurate estimates of fuel consumption for each of the fishing trips. In this regard, only the burning of fuel during the fishing operation was calculated, without considering navigation time from the port to fishing areas. According to Bail and Branco (2007), the navigation time ranges from 20 min to 1 h 30 min, which would certainly increase the consumption and emission values. This difficulty is also observed when assessing industrial fleets (Port et al. 2016), since, according to Notti et al. (2012), fuel consumption in this modality can be three times higher during the trawling operation than during navigation between ports and fishing areas.

During the study period (1996-2015), the artisanal fleet of Armação do Itapocoroy consisting of around 78 vessels per year with engine power between 10 and 60 Hp landed 148,082 t of fish, of which 19,002 t were seabob shrimp. These total landed biomass values account for 0.019% of the annual average landed by industrial trawling in Santa Catarina, which operated from 2003 to 2011 with an average of 358 vessels per year with engine power between 107 and 750 Hp (Port et al. 2016). In the same period, this artisanal fleet consumed 3,908,958.90 l of fuel, representing 1.24% of the annual average of the entire industrial trawl fleet of Santa Catarina between 2003 and 2011 (Port et al. 2016). Although this percentage seems small when compared to the industrial fleet, it should be stressed that artisanal trawl fishing communities were scattered throughout the state of Santa Catarina resulting in very high fuel consumption values.

The energy efficiency of the artisanal fleet of Armação do Itapocoroy proved to be very low. In the study period, approximately 26.4 l of fuel were consumed per kilogram of fish landed. Considering only the target species *Xiphopenaeus kroyeri*, the resulting energy efficiency is 205.71 l t^{-1} of landed shrimp. In contrast, the Santa Catarina industrial trawl fleet proved much more efficient, with 413 l of fuel per ton of fish landed (Port et al. 2016). Furthermore, the low energy efficiency calculated in this study is striking when compared with the efficiency recorded in Sweden by Ziegler and Hansson (2003) and Tyedmers (2004), totaling 1,410 l t^{-1}; on a global average and in European fisheries recorded by Degnbol (2009), ranging from 640 and 4,710 l t^{-1} of fish landed; in Japan by Furuya et al. (2011), ranging from 280 to 1,500 l t^{-1}; and a worldwide average recorded by Tyedmers et al. (2005), totaling 620 l of fuel per ton of fish landed.

The energy efficiency of the trawl fleet is generally deficient, because of the behavior of the variability patterns of stock captures (aggregations and distances to fishing areas) and the significant drag force produced during fishing operations, which require a great power of engine and high fuel consumption (Wileman 1984; Tyedmers 2004). For the Armação do Itapocoroy fleet, as well as for several others throughout the country, the trawling activity has only remained economically viable due to the existence of a constant incentive from the government through a fuel subsidy policy consisting of total tax exemption for the acquisition of oil. Furthermore, the economic sustainability of this fishery is strongly related to the sale of the various species of fish caught.

Fuel consumption of the artisanal trawl fleet resulted in average annual carbon emission of 0.144 GgC and 527.123 t CO_2 into the atmosphere. These figures represent 1.25 % of the average annual values of carbon and CO_2 emissions of the industrial trawl fleet of Santa Catarina (Port et al. 2016). As mentioned earlier, the number of fishing communities scattered throughout the state should be acknowledged.

Average per year carbon emissions from the artisanal fleet were 174,750 GgC for each GgC of total biomass landed; moreover, a great imbalance was observed between the amount of carbon emitted and removed resulting from total catches, indicating that the energy efficiency of this modality is poor due to high fuel consumption, among other factors (Wileman 1984; Tyedmers 2004). According to Azevedo et al. (2014), fuel consumption can amount to between 61.1% and 74.9% of the operating costs of the seabob shrimp fishing fleet, which reinforces the importance of carrying out specific and detailed studies on the behavior of this input.

Variables included in the list of impacts caused by this fishing activity can support more assertive decision-making for fisheries management and help define public management policies that consider economic, social, and environmental impacts.

Although artisanal fishing fleets, in particular trawling, consist of small vessels, their negative environmental impacts should not be overlooked, either due to the removal of considerable volumes of biomass, which in the case of trawling is aggravated by the lack of selective gear, or due to the emission of carbon and other greenhouse gases.

Therefore, fisheries must also be characterized according to fuel consumption and their relationship with the landed biomass to understand the real negative impacts beyond the catch of target or incidental species, among other factors. This characterization would support the creation of public policies for fisheries management and species conservation, both to maintain stocks and to minimize/neutralize emissions resulting from the use of fossil fuels.

Finally, the negative balance between carbon emission and removal reinforces the urgent need to develop selective technologies for trawl fishing gear. This measure would enhance the economic feasibility of the activity through the cost-yield ratio and would effectively reduce the capture of non-target species that play a fundamental ecological role in the balance of ecosystems.

ACKNOWLEDGEMENTS

The authors thank the trawl fishermen for their invaluable contribution and knowledge on fisheries. We are also grateful to Everton Della Giustina and Daniela M. G. Nunes (EPAGRI – Agricultural Research and Rural Extension Company of Santa Catarina) for providing us with some important data. J. O. Branco thanks the National Council for Scientific and Technological Development (CNPq) for the productivity grant and the University of Vale do Itajaí (Univali) for their support. D. Port thanks the Coordination of Superior Level Staff Improvement (CAPES) for granting the Postdoctoral fellowship.

REFERENCES

ABDALLAH PR, BACHA CJC. 1999. Evolução da atividade pesqueira no Brasil: 1960-1994. Rev Teor Evid Econ. 7 (13): 9-24.

ACAUAN RC, BRANCO JO, TEIXEIRA B, RODRIGUES FILHO JL, POLETTE M. 2018a. A pesca artesanal no município de Penha (SC): uma releitura do contexto socioeconômico da atividade e da capacidade adaptativa do setor. Desenvolv Meio Ambiente 49: 150-166. doi:10.5380/dma.v49i0.58078

ACAUAN RC, TEIXEIRA B, POLETTE M, BRANCO JO. 2018b. Aspectos legais da pesca artesanal do camarão sete-barbas no município de Penha, SC: o papel do defeso. Interações. 19 (3): 543-556. doi:10.20435/inter.v19i3.1581

ALMEIDA LR, BRANCO JO. 2002. Aspectos biológicos de *Stellifer stellifer* na pesca artesanal do camarão sete-barbas, Armação do Itapocoroy, Penha, Santa Catarina, Brasil. Rev Bras Zool. 19 (2): 601-610. doi:10.1590/S0101-81752002000200016

ÁLVARES JÚNIOR OM, LINKE RRA. 2002. Metodologia simplificada de cálculo das emissões de gases do efeito estufa de frotas de veículos no Brasil. CETESB, São Paulo. 12 p.

AZEVEDO VG, BARBOSA MN, ABDALLAH PR, ROSSI-WONGTSCHOWSKI CLDB. 2014. Custos operacionais de captura da frota camaroeira do litoral norte do estado de São Paulo: análise comparada entre valores de mercado e valores de cooperados. Braz J Aquat Sci Technol. 18 (1): 71-79. doi:10.14210/bjast.v18n1.p71-79

BAIL GC, BRANCO JO. 2003. Ocorrência, abundância e diversidade da ictiofauna na pesca do camarão sete-barbas, na Região de Penha, SC. Notas Téc. FACIMAR. 7: 73-82. doi:10.14210/bjast.v7n1.p73-82

BAIL GC, BRANCO JO. 2007. Pesca artesanal do camarão sete-barbas: uma caracterização sócio-econômica na Penha, SC. Braz. J Aquat Sci Technol. 11 (2): 25-32.

BARRILI GHC, FILHO JLR, DO VALE JG, PORT D, VERANI JR, BRANCO JO. 2021. Role of the habitat condition in shaping of epifaunal macroinvertebrate bycatch associated with small-scale shrimp fisheries on the Southern Brazilian Coast. Reg Stud Mar Sci. 43. doi:10.1016/j.rsma.2021.101695

BRANCO JO. 2005. Biologia e pesca do camarão sete-barbas *Xiphopenaeus kroyeri* (Heller) (Crustacea, Penaeidae), na Armação do Itapocoroy, Penha, Santa Catarina, Brasil. Rev Bras Zoo. 22: 1050-1062. doi:10.1590/S0101-81752005000400034

BRANCO JO, FRACASSO HAA. 2004. Ocorrência e abundância da carcinofauna acompanhante na pesca do camarão sete-barbas, *Xiphopenaeus kroyeri* Heller (Crustacea, Decapoda), na Armação do Itapocoroy, Penha, Santa Catarina, Brasil. Rev Bras Zool. 21 (2): 295-301. doi:10.1590/S0101-81752004000200022

BRANCO JO, VERANI JR. 2006. Pesca do camarão sete-barbas e sua fauna acompanhante, na Armação do Itapocoroy, Penha, SC. In: BRANCO JO, MARENZI AWC, organizers. Bases ecológicas para um desenvolvimento sustentável: estudos de caso em Penha, SC. Itajaí: Editora da UNIVALI. p. 153-170.

BRANCO JO, SANTOS LR, BARBIERI E, SANTOS MCF, RODRIGUES-FILHO JL. 2013. Distribuição espaço-temporal das capturas do camarão sete-barbas na Armação do Itapocoroy, Penha, SC. Bol Inst Pesca. 39 (3): 237-250.

BRASIL. 1999. Ministério de Minas e Energia. Balanço energético nacional. Brasília. 153 p.

BRASIL. 2006. Ministério da Ciência e Tecnologia. Emissões de dióxido de carbono por queima de combustíveis: abordagem top-down. Instituto Alberto Luiz Coimbra de Pós-Graduação e Pesquisa em Engenharia - COPPE. Rio de Janeiro-RJ.

COELHO VF, BRANCO J, HARMS DIAS MA. 2016. Indicadores de produtividade aplicados à pesca artesanal do camarão sete-barbas, Penha, SC, Brasil. Rev Ambient Água. 11 (1): 98-109. doi:10.4136/ambi-agua.1659

CROWDER LB, HAZEN EL, AVISSAR N, BJORKLAND R, LATANICH C, OGBURN MB. 2008. The impacts of fisheries on marine ecosystems and the transition to ecosystem-based management. Annu Rev Ecol Evol Syst. 39: 259-78. doi:10.1146/annurev.ecolsys.39.110707.173406

DEGNBOL P. 2009. Climate change and fisheries management. In: Abstracts from workshop on changes in marine and terrestrial productivity under climate change impact and feedback, Technical University of Denmark, 12 13 May. p. 15-16.

DIAS NETO J, OLIVEIRA DIAS J DE F. 2015. O uso da biodiversidade aquática no Brasil: uma avaliação com foco na pesca. Brasília: Ibama. 288 p.

[EPE] EMPRESA DE PESQUISA ENERGÉTICA. 2011. Balanço energético nacional 2011: ano base 2010. Rio de Janeiro. 266 p.

[FAO] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. 2007. The State of World Fisheries and Aquaculture 2006. Rome. 162 p.

[FAO] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS. 2020. The State of World Fisheries and Aquaculture, sustainability in action. Rome. 224 p. doi:10.4060/ca9229en

FIEDLER FN, PAZETO DM, LACERDA LLV. 2020. High mortality rates of *Chelonia mydas* in a small-scale bottom gillnet fishery in the southwest Atlantic Ocean. Aquatic Conserv: Mar Freshw Ecosyst. 30 (19): 1902-1909.

FIEDLER FN, PORT D, GIFFONI B, SALES G, FISH F. 2017. Pelagic longline fisheries in southeastern/south Brazil. Who cares about the law? Mar Policy. 77: 56-64.

FIEDLER FN, SALES G, GIFFONI BB, MONTEIRO-FILHO ELA, SECCHI ER, BUGONI L. 2012. Driftnet fishery threats sea turtles in the Atlantic Ocean. Biodivers Conserv. 21: 915-931.

FULTON S. 2010. Fish and fuel: life cycle greenhouse gas emissions associated with icelandic cod, alaskan pollock, and alaskan pink salmon fillets delivered to the United Kingdom [master thesis]. Dalhousie University Halifax, Nova Scotia. 123 p.

FURUYA A, FUKAMI M, ELLINGSEN H, KAGAYA S. 2011. A survey on energy consumption in fisheries, and measures to reduce CO_2 emissions. ERSA conference papers (ersa11p1322), European Regional Science Association. [accessed 2021 December 10]. http://www-sre.wu.ac.at/ersa/ersaconfs/ersa11/e110830aFinal01322.pdf.

GARCIA SM, GRAINGER RJR. 2005. Gloom and doom? The future of marine capture fisheries. Philos Trans Roy Soc. B. 360: 21-46. doi:10.1098/rstb.2004.1580

GRAFTON RQ, HILBORN R, RIDGEWAY L, SQUIRES D, WILLIAMS M, GARCIA S, GROVES T, JOSEPH J, KELLEHER K, KOMPAS T, et al. 2008. Positioning fisheries in a changing world. Mar Policy. 32: 630-634. doi:10.1016/j.marpol.2007.11.003

Haimovici M, Cergole MC, Lessa R, Madureira LS, Jablonski S, Rossi-Wongstchowski CLDB. 2006. Capítulo 2. Panorama Nacional. In: MMA/SQA. Programa REVIZEE: Avaliação do Potencial Sustentável de Recursos Vivos na Zona Econômica Exclusiva. Relatório Executivo. p. 79-126.

Hall MA, Alverson DL, Metuzals KI. 2000. By-catch: problems and solutions. Mar Pollut Bull. 41: 204-219.

[IBGE] Instituto Brasileiro de Geografia e Estatística. 2017. Estimativas da população residente com data de referência 1º de julho de 2017. Diretoria de Pesquisas, Coordenação de População e Indicadores Sociais. [accessed 2021 November 8]. http:// cod.ibge.gov.br/2VVPS.

[IPCC] Intergovernmental Panel on Climate Change. 1996. Good practice guidance and uncertainty management in national greenhouse inventories. Revised 1996 IPCC Guidelines for National Greenhouse Gas. London: United Nations Environment Program, the Organization for Economic Co-operation and Development and The International Energy Agency.

Jha PN, Edwin L. 2019. Energy use in fishing. In: Edwin L, Thomas SN, Remesan MP, Muhamed Ashraf P, Baiju MV, Manju Lekshmi N, Madhu VR, editors. ICAR Winter school training manual. Responsible fishing: Recent advances in resource and energy conservation. Kochi: ICAR-CIFT. p. 159-166.

Kaiser MJ. 2019. Recent advances in understanding the environmental footprint of trawling on the seabed. Can J Zool. 97 (9): 755-762. doi:10.1139/cjz-2018-0248

Kaiser MJ, Clarke KR, Hinz H, Austen MCV, Somerfield PJ, Karakassis I. 2006. Global analysis of response and recovery of benthic biota to fishing. Mar Ecol Prog Ser. 311: 1-14. doi:10.3354/meps311001

Kelleher K. 2008. Descartes en la captura marina mundial. Una actualización. FAO Fish Tech Pap. 470. 147 p.

Macêdo RF. 2004. Inventário de emissões de dióxido de carbono (CO_2) geradas por fontes móveis no estado do Rio Grande do Norte - período de janeiro de 2003 a junho de 2004. Holos. 2. doi:10.15628/holos.2004.35

Medeiros RP, Serafini TZ, McConney P. 2014. Enhancing Ecosystem stewardship in small-scale fisheries: prospects for Latin America and the Caribbean. Desenvolv Meio Ambiente. 32. doi:10.5380/dma.v32i0.38819

Menezes NA, Buckup PA, DE Figueiredo JL, DE Moura RL, editors. 2003. Catálogo das espécies de peixes marinhas do Brasil. São Paulo, Museu de Zoologia USP. 160 p.

Notti E, Sala A, Buglioni G. 2012. Energy audits on board fishing vessels: energy profiling can lead to reduced fuel consumption. Eurofish Mag. 6: 27-29.

Oliveira LEIS M, Barragán-Paladines MJ, Saldaña A, Bishop D, Jin JH, Kereži V, Agapito M, Chuenpagdee R. 2018. Overview of small-scale fisheries in Latin America and the Caribbean: Challenges and Prospects. In: Salas S, Barragán-Paladines MJ, Chuenpagdee R, editors. Viability and sustainability of small-scale fisheries in Latin America and the Caribbean. MARE Publication Series 19.

Ostrom E. 2007. A diagnostic approach for going beyond panaceas. PNAS. 104 (39): 15181-15187. doi:10.1073/pnas.0702288104

Parker RWR, Blanchard JL, Gardner C, Green BS, Hartmann K, Tyedmers PH, Watson RA. 2018. Fuel use and greenhouse gas emissions of world fisheries. Nature - Climate Change. 8: 333-337. doi:10.1038/s41558-018-0117-x

Pauly D, Christensen V. 1995. Primary production required to sustain global fisheries. Nature. 374: 255-257. doi:10.1038 /376279b0

Pauly D, Christensen V, Dalsgaard J, Froese R, Torres F. 1998. Fishing down marine food webs. Science. 279: 860-863. doi:10.1126/science.279.5352.860

PAULY D, WATSON R, ALDER J. 2005. Global trends in world fisheries: impacts on marine ecosystems and food security. Philos Trans Roy Soc. B. 360: 5-12. doi:10.1098/rstb.2004.1574

[PCSPA-SC] PROJETO DE CARACTERIZAÇÃO SOCIOECONÔMICA DA ATIVIDADE DE PESCA E AQUICULTURA. 2015. Relatório Técnico Final Vol. 1. BR 04042006/14, junho/2015. 1200 p.

PEREZ JAA, PEZZUTO PR, WAHRLICH R, SOARES ALS. 2009. Deep-water fisheries in Brazil: history, status and perspectives. Lat Am J Aquat Res. 37 (3): 513-542. doi:10.3856/vol37-issue3-fulltex-17

PINTO FCV, SANTOS RNS. 2004. Potenciais de redução de emissões de dióxido de carbono no setor de transportes: um estudo de caso da ligação hidroviária Rio-Niterói. Engevista. 6 (3): 64-74. doi:10.22409/engevista.v6i3.145

[PMAP-SC] PROJETO DE MONITORAMENTO DA ATIVIDADE PESQUEIRA NO ESTADO DE SANTA CATARINA. 2020. Relatório Técnico Final, Vol. 1, Monitoramento da atividade pesqueira, BR 08042054/20. Outubro 2020. 78 p.

PORT D. 2015. O impacto da pesca industrial de arrasto sobre os ecossistemas da margem continental do Sudeste/Sul do Brasil [PhD thesis]. Universidade do Vale do Itajaí. 161 p.

PORT D, PEREZ JAA, DE MENEZES JT. 2016. Energy direct inputs and greenhouse gas emissions of the main industrial trawl fishery of Brazil. Mar Pollut Bull. 107: 251-260. doi:10.1016/j.marpolbul.2016.03.062

SALAS S, BARRAGÁN-PALADINES MJ, CHUENPAGDEE R, editors. 2018. Viability and sustainability of small-scale fisheries in Latin America and the Caribbean. MARE Publication Series. Springer International Publishing AG. doi:10.1007/978-3-319-76078-0_1

SALAS S, CHUENPAGDEE R, SEIJO JC, CHARLES A. 2007. Challenges in the assessment and management of small-scale fisheries in Latin America and the Caribbean. Fish Res. 87: 5-16. doi:10.1016/j.fishres.2007.06.015

SALES G, GIFFONI BB, FIEDLER FN, AZEVEDO VG, KOTAS JE, SWIMMER Y, BUGONI L. 2010. Circle hook effectiveness for the mitigation of sea turtle bycatch and capture of target species in a Brazilian pelagic longline fishery. Aquatic Conserv: Mar Freshw Ecosyst. 20: 428-436. doi:10.1002/aqc.1106

SCHAU EM, ELLINGSEN H, ENDAL A, ASNONDSEN S. 2009. Energy consumption in the Norwegian fisheries. J Clean Prod. 17: 325-334. doi:10.1016/j.jclepro.2008.08.015

SQUIRES D. 2009. Opportunities in social science research. In: BEAMISH RJ, ROTHSCHILD BJ, editors. The future of fisheries science in North America. Fish Fish. Series 31. New York: Springer Science. 752 p.

SUURONEN P, CHOPIN F, GLASS C, LØKKEBORG S, MATSUSHITA Y, QUEIROLO D, RIHAN D. 2012. Low impact and fuel efficient fishing: looking beyond the horizon. Fish Res. 119: 135-146. doi:10.1016/j.fishres.2011.12.009

THURSTAN RH, BROCKINGTON S, ROBERTS CM. 2010. The effects of 118 years of industrial fishing on UK bottom trawl fisheries. Nat Commun. 1: 1-6. doi:10.1038/ncomms1013

TYEDMERS P. 2004. Fishing and energy use. Encyclopedia of energy. Vol. 2. Amsterdam: Elsevier. p. 683-693.

TYEDMERS P, PARKER R. 2012. Fuel consumption and greenhouse gas emissions from global tuna fisheries: a preliminary assessment. ISSF Technical Report 2012 03. International Seafood Sustainability Foundation, McLean, Virginia.

TYEDMERS P, WATSON R, PAULY D. 2005. Fueling global fishing fleets. Ambio. 34 (8): 635-638. doi:10.1639/0044-7447(2005)034[0635:FGFF]2.0.CO;2

WILEMAN D. 1984. Project oilfish. Investigation of the resistance of trawl gear. The Danish Institute of Fisheries Technology. 42 p.

WINTHER U, ZIEGLER F, SKONTORP HOGNES E, EMANUELSSON A, SUND V, ELLINGSEN H. 2009. Carbon footprint and energy use of Norwegian seafood products. SINTEF Report Nr. SHF80 A096068. 91 p.

ZAMBONI A, DIAS M, IWANICKI L. 2020. Auditoria da pesca: uma avaliação integrada da governança, da situação dos estoques e das pescarias. First ed. Oceana Brasil, Brasília. [accessed 2021 December 21]. https://static.poder360.com.br/2021/04/auditoria-da-pesca-brasil-2020.pdf.

ZIEGLER F. 2006. Environmental life cycle assessment of Norway lobster (*Nephrops norvegicus*) caught along the Swedish west coast by creels. Conventional trawls and species-selective trawls: a data report SIK report 746. SIK. Göteborg. 36 p.

ZIEGLER F, HANSSON P-A. 2003. Emissions from fuel combustion in Swedish cod fishery. J Clean Prod. 11: 303-314. doi:10.1016/S0959-6526(02)00 050-1

ZIEGLER F, VALENTINSSON D. 2008. Environmental life cycle assessment of Norway lobster (*Nephrops norvegicus*) caught along the Swedish west coast by creels and conventional trawls - LCA methodology with case study. Int J Life Cycle Assess. 13: 487-497.