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Research Article

Calculating the carbon footprint of the artisanal common hake fishery (*Merluccius gayi gayi*) in Caleta Portales, Valparaíso, Chile

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ABSTRACT. Society's awareness of environmental issues increases every day. In this context, the concept of carbon footprint (CF) arises as a calculation tool that quantifies greenhouse gasses (GHG) emitted during the life cycle (LC) of a product. This calculation method is used in many productive sectors throughout the world; however, the Chilean fisheries sector has not notified the use of this tool or initiatives in that sense. This study performs a calculation of the CF of artisanal gillnet hake (*Merluccius gayi gayi*) fishery of the Caleta Portales, located in Valparaíso, Chile. The ISO 14040: 2006 methodology was used. The analysis was limited from the boat departure until the catch is landed, as a gate-to-gate life cycle assessment (LCA). The fuel consumption data and information related to the fleet were used as the main source of information. The Caleta Portales hake landings were 1,340.484 kg in 2011 and 703,411 kg in 2012. This fleet released into the atmosphere in 2011, 0.47 CO_2 equivalent per kg of hake landed, and 0.58 kg CO_2 eq, in 2012. It is the first result of CF reported in a Chilean fishery. This result can lead to an increase in the competitiveness of this hake fishery, as it can generate a positive impact on encouraging consumers to prefer the consumption from those places that have calculated the CF and are less than other food products.

Keywords: *Merluccius gayi gayi*; carbon footprint; hake; artisanal fishing; life cycle assessment; Valparaíso; Chile

INTRODUCTION

Since the mid-1990s, increasing global concern about greenhouse gas rises in the atmosphere is recognized as one of the most critical factors in climate change. At the same time, methods to quantify such gases have been developed, and ways to reduce them have been sought.

At the beginning of the decade of 2000, the ecosystem approach to fisheries management was implemented. This approach requires understanding and quantifies the fisheries' impacts on the environment. In particular, policy-makers and the general public have come to recognize climate change as the single most critical environmental issue in the world today (Tan & Culaba 2009, Avadí & Fréon 2013).

Life cycle assessment (LCA) is a methodological tool used to measure a product, process, or system environmental impact throughout its entire life cycle (Ihobe 2009). An analysis of some stages can also be performed. System limits must be established to determine the scope of the analysis and data required performing an LCA, and the functional unit must be identified. The LCA of a product includes all inputs/outputs of the processes included in its life cycle, namely, the extraction of raw materials and the manufacture of the components, the end use of the pro-

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duct, and its recycling and final management. Transportation, storage, distribution, and other intermediate activities performed during the life cycle are also included when they are relevant. This life cycle is referred to as "cradle to grave" (raw materials until disposal). When the system scope is limited to the inputs/outputs from which the raw materials are obtained until the product is placed on the market (as the output of the manufacturing/assembly plant), it is referred to as "cradle to gate" (raw materials until factory gate). When only focusing on the manufacturing processes, it is referred to as "gate to gate" (Fig. 1).

LCA is thus a tool aimed to, among other purposes, identify opportunities for improvement and inform decision-makers on the environmental performance of products or systems (ISO 14044, 2006). Moreover, it can assist in selecting environmental performance indicators (e.g. for sustainability assessment) and for marketing purposes (ISO 14025, 2006).

The first life cycle assessment research in aquaculture and fisheries was applied in 2003, 10 years after the first agricultural and food products research (Avadí & Fréon 2013). Due to restrictions to access input/output data to perform a product or system life cycle, being restricted to some stages, the complete analysis is often not achieved.

The concept of carbon footprint (CF) is considered a simplified version of a life cycle analysis, in which, instead of considering several categories of environmental impact at the same time, only consider the relation to global warming and measures the total amount of greenhouse gases (GHG) emitted by the direct or indirect effect of an individual, organization, event or product (Ihobe 2009). CF includes all GHGs that contribute to global warming, including CO_2, but the individual results of each gas are referred to as CO_2 equivalent.

The incentives to calculate the product CF have come mainly from the global trade or consumer organizations, which prefer products environmentally friendly. The best approach to quantify GHGs is to calculate the CF that occurs in any productive activity. In this sense, the environmental impact of human activities can be measured by carrying out an inventory of GHG emissions. The CF is a quantified indicator that can be considered in the decision-making processes (Schneider & Samaniego 2009, Vázquez-Rowe et al. 2013) of the productive sector of companies or the administrative sector of economic activity at the governmental level, especially in countries in which foreign trade is an important element of the economic matrix.

Fishing uses fossil fuels as its main source of energy and is an important GHG emitter (Dutilh & Kramer 2000, Wilson 2005, Harman et al. 2008, Tan & Culaba 2009, Iribarren et al. 2010). Thus, the CF approach is closely associated with fisheries LCA due to the strong impact of fuel consumption (Avadí & Fréon 2013). Usually, the highest fuel consumption in the production cycle of sea products occurs in the extraction (Andersson 2000), with a very high level of emissions. Therefore, those fisheries that consume relatively less fuel not only have a lower CF, up to the point of landing but are also in a favorable position to meet future fuel and emissions regulations and may be more resilient to the effects of volatile fuel prices (Ziegler et al. 2013, Parker et al. 2014). The CF in fisheries depends on many factors: target species, fishing gears, distance to the fishing ground, skipper behavior, and other factors.

In several fisheries worldwide, efforts have been made to calculate the CF, for example, in the coastal fisheries of Galicia-Spain of species such as horse mackerel (*Trachurus trachurus*), Atlantic mackerel (*Scomber scombrus*), European pilchard (*Sardina pilchardus*), and blue whiting (*Micromesistius poutassou*). Also, offshore fishing as European hake (*Merluccius merluccius*), megrims (*Lepidorhombus boscii* and *L. whiffiagonis*), and anglerfish (*Lophius budegassa* and *L. piscatorius*), deep-sea fishing as skipjack (*Katsuwonus pelamis*) and yellowfin tuna (*Thunnus albacares*), extensive aquaculture as mussels (*Mytilus galloprovincialis*), and intensive aquaculture as turbot (*Psetta maxima*) (Iribarren et al. 2010) has been studied. In Norway, Ziegler et al. (2013) calculated the CF of more than 20 seafood products and different manufactures. Their results show that the final transportation of the product is an important factor because the most efficient seafood product was herring shipped frozen in bulk to Moscow with 0.7 kg CO_2 equivalents per kilogram (kg CO_2 eq kg^{-1}) edible product. At the other end is the fresh gutted salmon airfreighted to Tokyo with 14 kg CO_2 eq kg^{-1} edible product. In Thailand, Mungkung et al. (2012) made a comparative analysis of the CF using the PAS 2050:2008 standard of meat from individual quick-frozen fried chicken and canned tuna in sunflower oil.

The LCA can also be useful for the management of fisheries. An example of this is the rock lobster (*Jasus edwardsii*) fishery of Tasmania (Farmery et al. 2014). In that study, the authors concluded that the contribution to the fishery's footprint was minimal regarding air transport for the distribution of the product.

Tan & Culaba (2009) compared the CF of the tuna fishery in the Philippines with purse-seine and long-line, concluding that the highest contribution to the CF

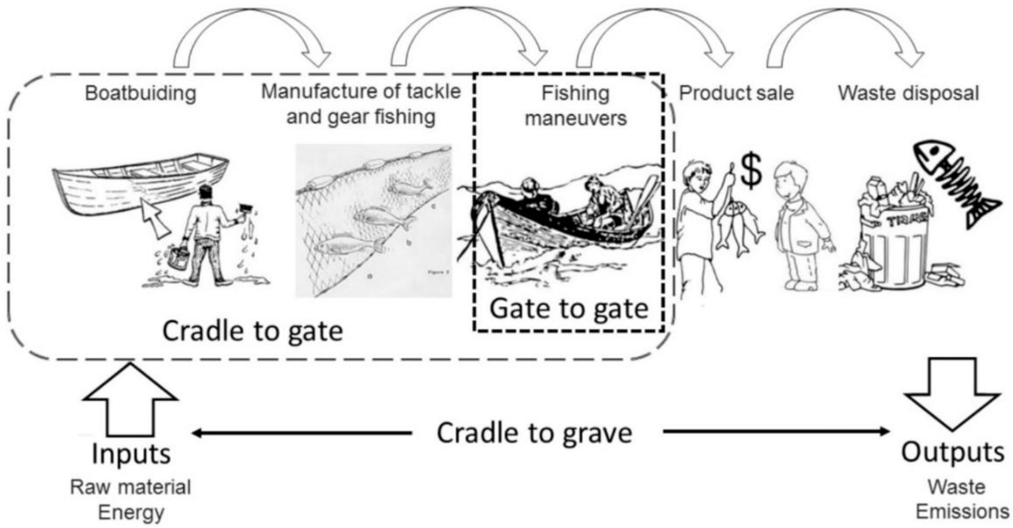

Figure 1. Terminology related to the scope of the life cycle assessment of hake gillnet fishing: (adapted from Ihohe S.A. 2009).

corresponds to fuel and that the purse-seine is the lowest fishing gear CF. Avadí & Fréon (2013) reviewed 16 studies on LCA applied to fisheries. Despite not being standardized, fishery-specific impact categories and fuel use in fishing operations were the main contributors to environmental impacts. Energy efficiency was found to be strongly related to the fishing gear used.

The Chilean fishing sector is an important socio-economic activity on the industrial and artisanal or small scales. The artisanal fishing sector plays an important role as a fresh fish supplier for direct human consumption in the domestic market. Common hake (*Merluccius gayi gayi*) is one of the preferred species for direct human consumption. National landings of common hake between the years 2007-2017, shows two periods, the first was prior to 2012 which registered values from 36,900 t in 2013 to 49,197 t in 2010 with a drastic reduction in the years 2014-2017, varying between 18,573 t in 2014 and 21,397 t in 2017. In the same period, the artisanal sector has represented between 36 and 41% of the total landings. The Caleta Portales artisanal fleet, with around 57 boats represented, for the same period, approximately 16-18% of the Valparaíso region fleet and between 4 and 5% of the national common hake artisanal fleet.

There have not been initiatives to quantify the CF of the country's fisheries until now in Chile. This work, makes one of the first contributions to reduce this gap, focusing on a small-scale fishery of the common hake that directly targets fresh consumption by humans and is commercialized in the domestic market.

The present work calculates the CF of the artisanal fleet using gillnets for fishing common hake from Caleta Portales of the Valparaíso region, Chile in years 2011 and 2012.

MATERIALS AND METHODS

Life cycle assessment

The system's limit studied corresponded to an analysis "from gate to gate," considering navigation from the cove to the fishing area; fishing maneuvers such as throwing, resting, and lifting the net; removing the net's capture; navigation to port; arriving and landing. The functional unit corresponds to one kilogram of common hake (*Merluccius gayi gayi*) landed.

Study area

The study area corresponds to the operational zone of the artisanal fleet that catches the common hake; the fleet operates out of Caleta Portales (33°01'52.74"S, 71°35'25.18"W), Valparaíso, Chile.

Characteristics and operational regime of the fleet

The fleet was characterized by a 2011 and 2012 survey of the fishermen on the fishery's boats that addressed their activity's technical and operational aspects. The census considered two aspects: the first related to the dimensions of the boats (total length, beam, and depth) and propulsion systems (brand, model, and power of the engines), which allowed a characterization of the fleet in terms of geometry and type of engines (Table 1); the second related to the operational and functional

Table 1. Geometrics characteristics of the boats that operated in 2011 and 2012, all the engines were outboard, and the hull material of all boats was fiberglass. *These boats operated only in 2011. **These boats operated only in 2012.

Boat name	Year of construction	Length (m)	Beam (m)	Height (m)	Engine brand	Power (HP)
Luis Alfredo	1970	7.00	1.65	0.50	YAMAHA	40
El Viejo Lalo I	1990	7.50	1.90	0.65	YAMAHA	75
Mónica Michel	1995	7.60	1.82	0.80	TOHATSU	50
Mamita Meche	1995	7.60	1.82	0.80	YAMAHA	40
María Eugenia	1995	7.56	2.60	1.20	YAMAHA	60
Raulito I	1995	6.80	1.90	0.75	TOHATSU	50
Andreita	1996	6.80	1.90	0.75	YAMAHA	50
Chamaco II	1996	6.80	1.90	0.75	YAMAHA	40
Ciclón	1996	6.80	1.90	0.75	SUZUKI	40
Insolencio II	1996	6.80	1.90	0.75	YAMAHA	60
Capitán Vitrola	1996	7.60	2.10	0.95	YAMAHA	60
El Saco	1996	6.80	1.90	0.75	YAMAHA	60
Simón Pedro	1999	7.60	1.82	0.80	YAMAHA	60
Ñatito Y Elsita	1996	7.60	1.82	0.80	YAMAHA	60
Santiaguillo II	1996	6.80	1.90	0.75	YAMAHA	40
Elda Cecilia	1996	7.60	1.82	0.80	YAMAHA	40
Camino Al Cielo	1996	7.60	1.80	0.80	SUZUKI	40
Pejerrey II	1996	6.80	1.90	0.75	YAMAHA	40
Lorena Paola	1996	7.60	1.82	0.80	YAMAHA	75
El Pele Chico II	1996	6.80	1.90	0.75	YAMAHA	60
Amalia Alejandra	1996	6.80	1.90	0.75	YAMAHA	40
Poseidón II	1997	7.60	1.82	0.80	YAMAHA	60
Elizabeth II	1997	7.60	1.82	0.80	YAMAHA	40
Abuelito Manuel	1997	7.60	1.82	0.80	YAMAHA	60
El Toño	1997	6.80	1.90	0.75	YAMAHA	60
Vitalia	1997	6.80	1.90	0.75	YAMAHA	40
Mamita Adriana	1997	6.80	1.90	0.75	JHONSON	55
Pato Lukas II	1998	6.80	1.90	0.75	YAMAHA	60
Peluquita II	1998	7.20	2.00	0.90	YAMAHA	60
Reinaldo José II	1998	7.90	1.50	0.90	YAMAHA	60
Diana I	1997	7.60	1.82	0.80	YAMAHA	60
Diana y Joseph (*)	2009	6.80	1.90	0.75	YAMAHA	40
Vania Kamila	1999	7.90	2.00	0.85	YAMAHA	40
Cecilia del Carmen	1999	8.10	2.00	0.85	YAMAHA	40
Charlotte II	1999	7.20	1.65	0.85	POWER TEC	40
Camilo	2000	7.60	1.82	0.80	YAMAHA	60
Pinocho	1999	7.00	2.00	0.85	YAMAHA	40
La Pepa II	2000	7.80	2.00	0.50	YAMAHA	48
Belén	2000	7.80	1.82	0.80	YAMAHA	40
Virginia	2001	7.90	1.61	0.80	YAMAHA	60
El Dragon	1996	6.80	1.90	0.75	YAMAHA	55
Ayax (**)	1983	7.20	2.86	0.65	YAMAHA	48
Mamita Luisa	2008	7.90	2.00	1.30	YAMAHA	75
Tío Pingo	2009	6.80	2.00	0.90	YAMAHA	40
El Cacique (*)	2011	7.90	2.20	0.85	YAMAHA	40
Doña Lolo	2010	7.90	2.00	0.85	TOHATSU	50
Ivana Catalina (**)	2010	8.35	2.20	0.80	YAMAHA	60
Fulminante I	2009	7.90	2.00	0.85	YAMAHA	60
Los Tres Hijitos (*)	1983	7.20	2.86	0.65	YAMAHA	48
Tres Hijitos I	2010	7.90	2.00	0.85	YAMAHA	48
Víctor Manuel	1999	6.80	2.00	0.90	YAMAHA	40
Viejo Lalo IV	2011	7.90	2.00	0.80	YAMAHA	40
Galilea (*)	1994	7.20	1.95	0.70	YAMAHA	48

Continuation

Boat name	Year of construction	Length (m)	Beam (m)	Height (m)	Engine brand	Power (HP)
Galilea II	2011	6.80	1.90	0.75	YAMAHA	48
Evelyn (*)	1995	6.80	1.90	0.75	MARINER	40
Evelyn II	2011	7.60	1.82	0.82	YAMAHA	40
Chino Gaby II (*)	1996	6,80	1,90	0,75	SUZUKI	60
Chino Gaby III	2011	7.90	2.20	0.85	TOHATSU	50
Simon Pedro I (**)	2011	8.49	2.45	0.92	YAMAHA	40
Don Horacio (**)	2009	7.90	2.00	0.85	TOHATSU	50
Ariel I (**)	2008	7.80	2.00	1.30	YAMAHA	40
Don Cristian II (**)	1994	7.20	1.95	0.70	YAMAHA	48
Johny Luis (**)	2009	6.80	1.90	0.75	YAMAHA	40

information about the fleet (fuel consumption per boat), gathering information on the fishing trips for each boat and the different activities involved to elaborate the operational regime of the fleet as a whole. Information was requested from users about time spent in each activity during fishing operations, use of the engine, and the fuel consumption in each outing.

Based on the operational regime and the duration of each activity in a fishing trip, the time of effective engine use was determined (engine hours), and this information was used to calculate the specific consumption per fishing leave of each boat (L h^{-1}). Together with the above, the background information indicated by the engine manufacturers in the catalogs was reviewed to obtain the design characteristics of the engines used by the users of Caleta Portales, including model, brand, specific consumption, and other technical characteristics.

Once the specific consumptions indicated by users and manufacturers were obtained, a comparison was made between those values, taking as a selection criterion the greater consumption to continue with the estimates. The above is based on the expected differences between the values reported by the manufacturers under standard conditions and the real value of operating consumption, thus preventing the total consumption of the fleet from being underestimated. Based on the specific consumption selected, the calculation of consumption per fishing trip of each boat (in liters) and the fleet as a whole was calculated.

The database of landings of common hake, registered and reported to the National Fisheries and Aquaculture Service (SERNAPESCA by its acronyms in Spanish) during 2011 and 2012, was asked to the manager of the Caleta Portales. The records are available daily and individualized by each boat, indicating the total landings in kilograms. This database also includes the number of fishing trips carried out during each year. Finally, based on total landing and total fuel consumption each year, the relation between landings and fuel consumption is obtained by boat, engine, and fleet as a whole.

The gillnet is the most used fishing gear by the artisanal fleet to catch common hake nationwide. This fishing gear is classified as passive and consists of a multifilament or monofilament nylon wall with a 6.25 cm mesh size (Gálvez et al. 2008, 2009), most used for its low visibility greater effectiveness in capture. The fishing tackle consists of an arrangement of a line of floats installed in the upper part of the mesh wall and a weights line in the lower part. This arrangement allows the net to remain vertical on the seafloor while it is in operation.

According to Queirolo et al. (2011), the fishing operation begins around 04:30 h with the departure of the boats from the cove. The fishing zone is located ~2 nm from the coast. Navigation to the fishing grounds is performed with GPS support. The resting time of the fishing gear varies between 1 and 1.5 h before returning to port between 09:00 and 10:00 h. Gillnet fish removal is done either onboard while lifting the net or inland after returning to the cove, depending on the catch volume.

From the operational regime and duration of each activity in a fishing trip, the effective time of use of the engines was determined, and this information was used to calculate the specific consumption per fishing trip of each boat (L h^{-1}).

In addition, depending on the models, brands, and power of the engines, the specific theoretical consumptions indicated by the manufacturers in the engine catalogs were reviewed. The specific consumptions of the engines declared by the users were compared with those indicated by the manufacturers. In the case of discrepancies, the highest value was adopted. In this way, we avoided underestimation of the total consumption of the fleet. With the specific consumption selected, the consumption per fishing output of each boat (liters) and the fleet as a whole are calculated. The cove managers provided monthly information with the number of fishing trips Made during 2011 and 2012.

Total consumption and consumption per unit landed (CUL) of the fleet

Information on the fishing effort and landings were obtained from the databases of landings per fishing trip from the official records of the SERNAPESCA (http://www.sernapesca.cl). This information is recorded daily by users in a daily fishing logbook and declared to SERNAPESCA by the cove's administration. The records are individualized by boat, indicating the total landing of the resource in kilograms.

The fishing effort (E) is equivalent to the number of fishing trips during the year, while the landing corresponds to the kilograms of hake unloaded and registers per boat and fishing trip. The total landings (L) per year correspond to the sum of yearly individual landings, according to the following equation:

$$E = \sum_{i,j=1}^{n} e_{i,j} \quad \text{and} \quad L = \sum_{i,j=1}^{n} l_{i,j}$$

where: $e_{i,j}$: effort of the i^{th} trip and j^{th} boat (number of fishing trips) and $l_{i,j}$: landing (kg) of the i^{th} trip of the j^{th} boat.

Fishing effort and landing were obtained monthly by type of engine and for the fleet as a whole to compare and establish efficiency ratios.

The consumption data are fishing trips; therefore, the average time of effective use of each boat engine (h_{engine}) during fishing trips in which catches are recorded is calculated. In this way, through the operational regime, the fuel consumed per hour use was performed. After defining activities in which the engine is effectively used, and the time used in each fishing maneuver, the above was possible. It is assumed that the distance traveled by the boat from the port to the fishing ground and vice versa is the same; therefore, the fuel consumption is the same in both navigations.

With the main characteristics of the engines used and engine hours, the specific consumption (L h^{-1}) of each engine is calculated from:

$$SC = \bar{C} / t_e; \; t_e = (2t_{nav} + t_{cal} + 0.5\, t_{vir})$$

where: $\bar{C}$: average fuel consumption per fishing trip (L); SC: specific fuel consumption (L h^{-1}); t_e: effective time (h) used in the fishing operation consuming fuel, from the departure to the arrival; t_{nav}: navigation time (h), multiplied by two (considered as round trip among the cove and the fishing ground); t_{cal}: throwing time (h) for the fishing rigging; t_{vir}: lifting time (h) for the fishing rigging.

During the boat's downtime, the engines are not used, so there is no fuel consumption, so time is not incorporated into the calculation. However, users indicate that the lifting of the net is done with the engine idling, which means a lower fuel consumption that could be half the consumption used in the other maneuvers; therefore, to avoid underestimating consumption, engine usage time was reduced by half.

Once the consumption of each boat was determined, the total hours worked per boat during 2012 was calculated based on the number of departures registered in the cove records. The annual fuel consumption per boat (tc_j) (L) was obtained according to:

$$tc_j = e_j\, h_{engine}\, c_j$$

where e_j: effort of the j-th boat (number of fishing trips), h_{engine}: total working hours of the j-th boat engine hours), c_j: individual consumption of each boat (L h^{-1}).

Then, the total annual consumption of the fleet (TC) (L) was obtained as:

$$TC = \sum_{j=1}^{n} tc_j$$

Considering the total consumption and the annual landing of the Caleta Portales fleet, consumption per unit landed (CUL) was determined according to:

$$CUL = TC/L$$

where: TC: total annual fuel consumption (L), L: total annual landings (kg).

Calculation of CF

The CF was calculated using the following formula:

$$CF = (AD)\,(EF)$$

where: CF: carbon footprint (kg CO_2), AD: activity data (L), EF: emission factor (kg CO_2 L^{-1}).

The AD is the parameter that defines the degree or level of activity generating GHG emissions (IPCC 2006). In this case, it corresponds to the fuel used in the fleet's engines to capture hake.

The EF corresponds to the amount of GHG emitted by each unit of the "activity data" parameter (IPCC 2006). These factors vary depending on the activity in question. In this case, the fuel used corresponds to 93 octane gasoline, with an emission factor of 2.38 kg CO_2 L^{-1} (IPCC 2006).

Finally, the CF per unit landed is obtained by dividing the total footprint by the total hake landed.

RESULTS

Characteristics of the common hake artisanal fleet operating in Caleta Portales

According to Pena et al. (2009), consumption will depend on the boat's dimensions, the operational regime, the fishing gear used, the propeller, and the boat's maintenance, and the engine, so the fleet was characterized to determine if this fleet was homogeneous.

Table 2. Summary of average geometrics characteristics of the Caleta Portales boats that operated on common hake *Merluccius gayi gayi* in 2011 and 2012 ($\bar{x}$: is the average of beam and depth).

Length (m)	Nº boats 2011	Nº boats 2012	Beam (m)			Depth (m)		
			$\bar{x}$	Min	Max	$\bar{x}$	Min	Max
6.8	21	19	1.91	1.90	2.00	0.77	0.75	0.90
7.0	2	2	1.83	1.65	2.00	0.68	0.50	0.85
7.2	4	4	2.12	1.65	2.86	0.78	0.65	0.90
7.5	1	1	1.90	1.90	1.90	0.65	0.65	0.65
7.6	15	15	1.89	1.80	2.60	0.84	0.80	1.20
7.8	2	3	1.91	1.82	2.00	0.65	0.50	0.80
7.9	10	10	1.95	1.50	2,20	0.89	0.80	1.30
8.1	1	1	2.00	2.00	2.00	0.85	0.85	0.85
8.4		1	2.20	2.20	2.20		0.80	0.80
8.5		1	2.45	2.45	2.45		0.92	0.92
Total	56	57		1.50	2.20		0.50	0.95

In 2011 and 2012, 56 and 57 common hake fishing boats operated in Caleta Portales, respectively (Table 1). Their construction ranges from 1970 to 2011, and all of the boats are fiberglass. The lengths of these boats vary between 6.8 and 8.5 m (Tables 1-2). The beam varies between 1.50 and 2.86 m, with most between 1.9-2.0 m, followed by 1.8-2.1 m. The depth of the boats was between 0.5 and 1.3 m, with most between 0.75 and 0.90 m.

The departure of most of the boats is recorded between 04:30 and 05:00 h in the morning; the navigation time (t_{nav}) lasts approximately 15 min. Within the fishing zone, the fishing ground is located, and the net is set in a throw time (t_{cal}) of approximately 10 min, which varies according to the net size. The net is left at rest (trep) once the throw is completed, for approximately 2 h, during which time the engine is off. After the resting time is over, the net is lifted to the boat; this corresponds to the lifting time (t_{vir}), approximately 1 h, and varies according to the catch volume. At this stage, the engine is idling, with minimum fuel consumption. During this stage, fish are removed from the net to be stored in plastic boxes. After the net has been lifted, the boat returns to the cove, where the catch is unloaded, and the remaining fish and bycatch are removed from the net, the net is checked, and any necessary repairs are made, leaving it ready for the next fishing trip.

Fuel consumption of the fleet

Based on the information provided by the fishermen, the average consumption per boat and type of engine was calculated. Thus, the lowest average consumption corresponded to the Suzuki 60 HP with 21.3 L h^{-1} followed by Yamaha 50 HP and Johnson 55 HP engines, with 22.5 L h^{-1}, while the highest was the Yamaha 55 HP and Mariner 40 engine, with 27.5 L h^{-1} each (Table 3). In cases in which the consumption was not provided by the manufacturers (Power Tec 40 and Suzuki 40), consumption was estimated using a linear adjustment with the available data, according to SC = 0.332 Pow + 6.392 (R^2 = 0.89) (SC: specific consumption (L h^{-1}), Pow: power (HP)).

In general, for the entire fleet, the fuel consumption declared by users is greater than that indicated by the manufacturers. From this point of view, Yamaha 75, Yamaha 60, and Yamaha 50, together with the Tomatsu 50, were the most efficient, although the differences are within the coefficient of variation (CV) of the consumption declared by the users. In contrast, the engines with the lowest efficiency were the engines with power less than 50 HP (PowerTec, Suzuki, and Yamaha). The above can be explained due to either the higher demand for engine power in adverse weather conditions that may be different from the manufacturers' efficiency tests or a greater requirement in the navigation to and from the fishing grounds.

Fishing effort and landing of the fleet

Official statistics indicate that during 2011 and 2012, Caleta Portales recorded a total landing of hake of 1,340.484 and 703,411 kg, respectively which were associated with a total of 8158 and 6478 fishing trips of the fleet as a whole (Tables 3-4). The largest landing took place in August, and the highest number of departures was also registered this month (Table 4). The lowest catch corresponds to June, which recorded the lowest number of fishing trips. In September, no landings were registered because the fishing season was closed.

In 2012, according to the type of engine, the Power Tec 40 showed a minimum of 58 fishing trips while

Table 3. Engines used by the artisanal hake *Merluccius gayi gayi* fleet; fuel consumption (consum) indicated by manufacturers and users; fishing trips and total hake landings by engine; time of use (h) of engines and landing of hake artisanal fleet of Caleta Portales in 2011 and 2012. *Values derived of regression SC = 0.332 Pow + 6.392 (R^2 = 0.89), SC: specific consumption (L h^{-1}), Pow: power (HP), SD: standard deviation, CV: coefficient of variation, Δ: difference between fuel consumption per catalog and declared.

	Power HP (Kw)	Fuel consum (L h^{-1})	Average fuel consum declared (L h^{-1})	SD	CV (%)	Δ (L)	2011 N° boats	2011 Fishing trips	2011 Landing (kg)	2011 Engine effective time used (h)	2011 Fuel consum (L)	2011 Consum/ landing (L kg^{-1})	2012 N° boats	2012 Fishing trips	2012 Landing (kg)	2012 Engine effective time used (h)	2012 Fuel consum (L)	2012 Consum/ landing (L kg^{-1})
Johnson 55	55 (40.5)	24.6*	22.5	-	-	2.1	1	188	30,444	188	4,632	0,15	1	132	14,066	132	3,630	0.26
Mariner 40	40(29.4)	19.7*	27.5			-7.8	1	164	23,070	185	6,765	0,29						
Power Tec 40	40 (29.4)	19.7	25.0	-	-	-5.3	1	168	24,412	221	4,582	0,19	1	58	4,966	68	1,333	0.27
Suzuki 40	40 (29.4)	19.7*	25.0	1.77	7	-5.3	2	385	59,564	477	9,373	0,16	2	351	35,490	336	9,653	0.27
Suzuki 60	60 (44.1)	26.3*	21.3	-	-	5.0	1	137	25,224	154	5,138	0.20						
Tohatsu 50	50 (36.8)	25.0	24.4	2.39	10	0.6	4	633	113,489	766	19,780	0,17	5	659	76,019	647	18,048	0.24
Yamaha 40	40 (29.4)	20.0	24.2	2.89	12	-4.2	19	2,610	439,599	3,335	85,057	0,19	20	2,097	233,317	2,045	47,984	0.22
Yamaha 48	48 (35.3)	21.0	24.0	1.37	6	-3.0	5	388	58,812	774	18,484	0,31	5	449	46,071	463	11,181	0.23
Yamaha 50	50 (36.8)	24.0	22.5	-	-	1.5	1	110	17,878	120	2,880	0,16	1	145	5,302	109	3,988	0.26
Yamaha 55	55 (40.5)	21.0	27.5	-	-	-6.5	1	193	30,668	237	5,790	0,19	1	70	5,788	85	1,776	0.31
Yamaha 60	60 (44.1)	25.5	24.6	3.77	15	0.9	17	2,742	447,066	3,063	85,266	0,19	18	2,267	246,966	2,283	63,434	0.25
Yamaha 75	75 (55.0)	34.0	25.8	6.29	24	8.2	3	440	70,258	474	16,105	0,23	3	250	25,427	271	9,219	0.42
Total							56	8,158	1,340,484	9,994	263,852	0.20	57	6,478	703,411	6,440	170,246	0.24

Yamaha 50 registered the lowest fishing trips in 2011. By other hand, Yamaha 60 engine performed the biggest fishing trips over the two years, followed by Yamaha 40 engine with 2610 in 2011 and 2097 fishing trips in 2012 (Table 3). The largest landing was registered with the Yamaha 60 HP, with a total of 447,066 kg in 2011 and 246,966 kg, in 2012 followed by Yamaha 40 HP engines, with 439,599 kg in 2011 and 233,317 kg in 2012. Both engines are the most used and represent more than 65% of the total landed in Caleta Portales.

Total consumption of fuel and consumption per unit landed

From the operational regime of the fleet and the total number of departures of the boats in 2011 and 2012, 9994 and 6440 h of total engine used were calculated. The Yamaha 60 and Yamaha 40 engines are the most frequently used in the fleet. Time used with these engines was over 3000 h in 2011and 2000 h in 2012, equivalent to 64% of the total engine hours used in 2011 and 67% in 2012. In contrast, the engines that registered less use correspond to the Yamaha 50 in 2011 (120 h) and Power Tec 40 and Yamaha 55, with 67.7 and 84.6 h, respectively, in 2012 (Table 3). From the hours of use and consumption per hour of each engine, the total annual consumption of the fleet was determined to be 263,852 L of fuel in 2011 and 170,246 L in 2012.

In terms of fuel consumption per quantity landed, in 2011 the Yamaha 75 engine had the highest consumption per kilogram landed with 0.23 L kg^{-1} while in 2012 had and 0.42 L kg^{-1}, followed by the Yamaha 48 in 2011 0.31 L kg^{-1} and Yamaha 55 engine 0.31 L kg^{-1} in 2012. The engines that recorded the lowest consumption per kg were Johnson 55 in 2011 with 0.15 L h^{-1} while in 2012 were Yamaha 40 0.22 L kg^{-1} and Yamaha 48 0.23 L kg^{-1} (Table 3).

The CF from fuel consumption

Considering the fuel consumptions and the operational regime of the fleet for 2011 and 2012 the fuel average fuel consumption was 0.20 L kg^{-1} in 2011 and 0.24 L kg^{-1} in 2012. By other side, considering the total landing per year and that the fuel used corresponds to 93 octane gasoline with an emission factor of 2.38 kg CO_2 L^{-1} (IPCC 2006), the estimated CF for the artisanal fleet of Caleta Portales was:

Year 2011: CF = 627,967.76 kg CO_2 eq and

Year 2012: CF = 405,185.48 kg CO_2 eq

Thus, the CF of 1 kg of common hake landed in 2011 is equal to 0.47 kg of CO_2 eq and in 2012 is 0.58 kg of CO_2 eq.

Table 4. Monthly landings of hake *Merluccius gayi gayi* and fishing trips in 2011 and 2012.

Month	2011		2012	
	Landing (kg)	Fishing trips	Landing (kg)	Fishing trips
January	137,628	875	56,740	492
February	163,596	829	85,529	591
March	170,954	837	78,598	737
April	132,842	899	58,067	610
May	124,548	897	54,630	604
June	91,914	742	33,802	422
July	92,516	727	57,260	589
August	158,216	825	94,855	794
September	0	0	0	0
October	125,107	575	64, 947	557
November	91,692	504	61,272	519
December	51,471	448	57,711	563
Total	1,340,484	8158	703,411	6478

DISCUSSION

The CF is a topic of public debate on climate change, attracting consumers, businesses, governments, non-governmental organizations, and international institutions (Peters & Hertwich 2008). CF is considered an important tool to quantify GHG emissions and manage this emission (Espíndola & Valderrama 2012). Developing countries have promoted the measurement of the CF in the private sector and are motivated to be prepared for future scenarios and improve their companies' competitiveness to maintain and access new markets. Thus, developed countries can reduce the competitiveness of exports from those countries that do not measure CF and reduce their emissions (Frohmann et al. 2012). In Latin America and the Caribbean, 52% of exports are to the USA and the European Union. These markets are greatly interested in measuring the carbon content integrated into goods and services to compare local and imported products (Frohmann et al. 2012).

Chile exports its resources to 97 countries, and discussions on this matter are not foreign to them; nevertheless, it is necessary to take concrete actions to make advances in determining the CF of fishing activities. In this regard, Tapia et al. (2013) note that in Chile, no research quantifies the CF of fishing activities and indicates the need to design strategies that reduce CO_2 emissions to improve the competitiveness of the productive sectors in the face of new market demands and consumer preferences who trend towards more environmentally friendly products. Soto & Quiñones (2013) suggest that applying CF reduction strategies to fisheries and aquaculture has garnered less attention due to these activities' low contribution of GHG emissions.

Existing methodologies recommend quantifying the emissions of a product or service through a complete life cycle assessment referred to as "cradle to grave." This process considers emissions from the acquisition of raw materials (construction of the boat and fishing gear and fishing rig) to the consumer's final disposal of the waste. However, according to the purpose of the system and the availability of information, this calculation can also be made by establishing the system's limits. For example, quantification can be from cradle to gate (from the boat construction fishing trips and fishing rig and fishing gear until the product is put on the market) or from the gate to gate (when only the productive system is considered, that is, from the departure of the boat to the landing of the catch). These methodologies exclude emissions derived from the production and maintenance of various categories of capital goods used in the life cycle of fishery and aquaculture products (e.g. buildings, boats, machinery, equipment, others) despite their significant contribution to GHG emissions. These latter methodologies are often used due to the complexity of performing the calculations associated with them and the lack of information (BSI 2012).

Given the above, the definition of the system's limits is critical because it defines the extension of the processes included in estimating GHG emissions; therefore, the CF of a system will depend on the established limits (Brenton et al. 2009).

However, there is a need to develop rules that are more specific than those established by the available standards, which allow the limitation of the degrees of freedom in the definition of the system's scope, the selection of the functional unit, the definition of rules of allocation, and the quality of the data, among other criteria, to avoid biased comparisons between products (Dias & Arroja 2012).

Regarding the results of this study, it can be concluded that the common hake *Merluccius gayi gayi* fishing boats operating in the Caleta Portales in the study period are quite homogeneous in terms of their geometric characteristics, verifying that two large boats were added in 2012 (Table 2), also the number of boats in the fleet remained practically unchanged in both years, with 56 and 57 boats.

Following the trend of recent years, the fleet operates with gillnets, applying a similar operational regime for all boats. However, the study showed a greater variety of engines used, particularly concerning their horsepower, which varies between 40 and 75 HP. Although there is a wide range of such engines, in this fleet, two-stroke 40 and 60 HP engines predominate. There is a preference for Yamaha engines (84%).

Regarding engine performance related to fuel consumption, it is important to have in mind that operating conditions are variable, and consumption will depend on the dimensions of the boat, the operational regime, the gear used, the propeller and the maintenance of the boat, and the engine (Pena et al. 2009).

Users indicate that during the gillnet lifting, the engine remains on, with lower performance than during the rest of the activities (in "idle"); however, consumption is uncertain during that period. In addition, the climatic conditions during the operation in each case are unknown. Thus, the discrepancy between what is indicated in the manufacturer's catalogs and what fishers describe concerning engine efficiency could be explained by differences in testing and operating conditions.

Regarding landing and fishing efforts, it is important to rely on the records to identify the daily activities carried out by each boat. Although Caleta Portales has an orderly and systematic information system, there is no difference between the days when the boats did not operate and that day when the boats did go out but did not catch common hake. For that reason, this study's fuel consumption calculations only included records with catch, which could underestimate the total consumption of the fleet. However, this underestimation is considered minimal because fishers seek to maximize the efficiency of their operations, thereby minimizing trips in which fishing is unproductive. However, the CF calculation for Caleta Portales fleet did not differentiate hake from other species caught, attributing all the fishing effort and fuel consumption to the fishing operations for the target species (hake), which may explain the overestimation of the CF in a proportion that cannot be determined because the data are aggregated. In this regard, it should be considered that the common hake is the dominant species, and the bycatch contributions are marginal and temporary. Consequently, improving the CF is essential to improve basic data on fuel consumption and catch both per species and per fishing trip.

The results of this investigation show that the gasoline consumption per kg landed was on average 0.20 L kg^{-1} in 2011 and 0.24 L kg^{-1} in 2012, values which are lower than the global average consumption by fisheries, which is estimated at 0.62 L kg^{-1} (Tyedmers et al. 2005).

Recent studies indicate that the use of fuel and consequently the carbon emissions in fishing activity vary according to the target species, where the fishing takes place and the fishing gear used (Tyedmers 2004, Tyedmers et al. 2005, Tan & Culaba 2009, Tyedmers & Parker 2012). For these reasons, values can be found ranging from 1 kg of CO_2 eq per kg landed for Spanish mussels, Northeast Atlantic mackerel, and Baltic herring to 86 kg CO_2 eq kg^{-1} for Norwegian lobster extracted by trawling (Nijdam et al. 2012). However, Tan & Culaba (2009) calculate the CF of tuna caught with purse seines at 1.15 kg of CO_2 eq per kg landed and the CF of tuna caught with long-line at 6.64 kg of CO_2 eq per kg landed. One of the main conclusions of this study is that the fuel consumption of the fishing fleet is usually the largest contributor to CF.

Other authors have also found that purse-seine fishing uses less fuel than long-line fishing and have estimated that between 60 and 90% of the life cycle emissions of fishery products of tuna come from fossil fuel consumption (Tyedmers & Parker 2012).

Regarding the differences in fuel consumption between fisheries that operate with gillnets and trawl, Ziegler & Hansson (2003) determine that fuel consumption for cod (*Gadus morhua*) fished with gillnets is 0.34 L kg^{-1} landed but is significantly higher for trawl fishing, reaching 1.41 L kg^{-1}. Bak (1994) also shows the same differences in consumption, recording lower fuel consumption when using gillnets (0.33 L kg^{-1}) than when using trawls (1.4 L kg^{-1}).

The results show that in 2012 the fishing trips were reduced by 20.6% compared to 2011 (Table 3), also verifying a reduction of 35.6% in the time used by the engines, therefore the fuel consumption decreased by a similar percentage (35.5%), this reduction explains the lower CF by 35.5% in 2012 (CF = 405,185.48 kg CO_2 eq) compared to 2011 (CF = 627,967.76 kg CO_2 eq). However, the higher catches in 2011, compared to 2012, determined that the CF referred to the functional unit (1 kg of hake landed) in 2011 was lower than in 2012.

These results suggest changes in the availability of common hake, which are consistent with the reduction of more than 4.4% of the annual national catch quota allocated to the artisanal sector from 16,296 t in 2011 to 15,575 t in 2012 (www.subpesca.cl). Although fuel consumption was higher in 2011 than 2012, it is concluded that the CF was higher in 2012, which is explained by the fact that the functional unit defined for the study corresponds to 1 kg of hake landed, therefore, higher consumption was associated with a bigger number of fishing trips and a higher hake landing. This leads to the conclusion that a factor that directly influences the CF is the state of the stock and management measures and fisheries administration, which depend on the available biomass.

The values obtained in this work rank much better than beef (30 kg of CO_2 eq kg^{-1} of product), pork (5.9 kg of CO_2 eq kg^{-1} of product), or chicken (2.7 kg of CO_2 eq kg^{-1} of product) (Cederberg et al. 2009). However, the production processes are different, and therefore the CF measurements are not comparable. The values of this study are similar to those found by Winther et al. (2009) for mackerel; that study's estimated CF is 0.54 kg of CO_2 eq per kg landed. As in this work, the CF calculation is based on the fleet fuel consumption, making them comparable.

It could also be concluded that the CF of the common hake in the Caleta Portales is less than aquaculture products such as Norwegian salmon, whose CF is 2.9 kg of CO_2 eq per kg landed (Winther et al. 2009). According to the Technological Center of Miranda de Ebro, the rainbow trout of Spain has a CF of 4.81 kg of CO_2 eq per live kg and 5.07 of CO_2 eq per kg of processed trout; this could be because the limits of the system to perform the CF calculation are broader since it includes a process line, which is not the case in the present study, in which the fish are sold fresh at the same place the catches are landed.

This study performs the calculation from when the boat departs to the fishing zone until it arrives to land the fish. Concerning to above, Harman et al. (2008) indicated that in the United Kingdom, the primary production phase (fishing) is the dominant source of GHG emissions associated with seafood products for human consumption. Processing and packaging generally contribute very little to emissions (less than 10%), except when dealing with high-emission materials such as metals or when cooking is required, among others (Harman et al. 2008). It is recommended to carry out a study in which a life cycle assessment is performed from the cradle to the grave.

It is also recommended to develop a methodology for constructing abatement curves of GHG emissions for the fishing sector. The greenhouse gas abatement cost curves provide a quantitative basis for discussions about what actions would most effectively reduce emissions and their cost. These provide a global map of opportunities to reduce greenhouse gas emissions. Abatement cost is defined as the additional costs (or perceived benefits) when replacing a reference technology with a low-emission alternative (Clerc et al. 2013).

Based on the results of this study, it is clear that to reduce GHG in the fishing sector of Caleta Portales; it would be advisable to replace the engines that consume the most fuel (Yamaha 55) with engines that consume the least fuel (Yamaha 50 and Johnson 55).

According to the engine, the relationship between fuel consumption and landings indicates how efficient the boat is in its fishing operations. Although fishing is an activity conditioned by the environment in which it develops, improving aspects such as speed reduction, preventive maintenance of the engine, or replacing the propeller with a more efficient one can ultimately reduce fuel consumption and the GHG emissions associated costs.

Iribarren et al. (2010) highlight the CF as a support tool for decision making within the fisheries sector, allowing the identification of opportunities for climate change mitigation.

For some, the CF measurement is a protectionist measure, whereas, for others, it is an opportunity to innovate, achieve better energy efficiency, diversify, add value, and gain competitiveness. Regardless of these considerations, this trend appears to be increasing worldwide, and therefore, producers should consider this issue in their business decisions (Frohmann et al. 2012).

Although this study corresponds to a simplified CF calculation of the common hake artisanal fishery based on fuel consumption, it represents the first approach that seeks a more detailed discussion of the subject. It is expected to drive future studies for main fisheries in the country that seek to position themselves in markets that demand (either now or in the future) the quantification and reduction of their CF.

Indeed, Chile has companies dedicated to calculating the CF for these purposes, but they refer to products that exclude fishing. However, it is necessary to visualize state incentives for organized fishers in artisanal fishing to support these initiatives and verify the greater benefits obtained. The first and most important step is to initiate or systematize the data required for the calculation to be centralized in the fishermen's base organizations.

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