ISSF Technical Report 2012-03

Fuel Consumption and Greenhouse Gas Emissions from Global Tuna Fisheries: A preliminary assessment

Results of a research project undertaken by:
Dr. Peter Tyedmers &
Mr. Robert Parker
School for Resource & Environmental Studies,
Dalhousie University, Canada

On behalf of:
International Seafood
Sustainability Foundation

2012

Suggested citation:
Tyedmers, P. and R. Parker. 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, USA.

Summary

Contemporary tuna fisheries are heavily dependent on fossil fuels for propulsion, fishing and related activities. This reliance on fossil fuels not only contributes to a range of environmental concerns, most notably climate change, but also makes many tuna fisheries vulnerable to fluctuations in global oil prices. This report presents the results of a research project which aimed to quantify the fuel use intensity and partial carbon footprint of tuna fisheries in 2009, and, where possible, describe how fuel use varies by species targeted, location of fishing, and gears employed. Results are based on analysis of industry surveys reporting catch and fuel use data, representing ~19% of global landings of major tuna species in 2009. Analysis shows that there is a clear and marked difference in fuel use intensity between what can be considered two broad classifications of tuna fisheries: those targeting primarily skipjack and yellowfin tuna with purse seine, and those targeting albacore and bluefin tuna with longline, troll, and pole and line gears. The former group, using purse seine gear, was found to burn, on average, 368 litres of fuel per live weight tonne of landings, while the latter group of fisheries using other gears was found to burn, on average, between 1070 (longline) and 1490 (pole and line) litres per tonne. While it is not possible to discern from these data whether the lower fuel use intensity of the purse seine fisheries is the direct result of the type of gear used or of the species targeted, the findings are in line with previous studies that have found purse seine fisheries to be associated with relatively lower fuel use when compared to longlining. Aggregated and applied to the global tuna fishing fleet, we estimate that the total global tuna fishery, up to the dock, burned approximately 3 billion litres of fuel in 2009, and produced approximately 9 million tonnes of carbon dioxide equivalent greenhouse gas emissions from burning fuel. While the energy demands of tuna fisheries are substantial and, in some cases, much higher than other fisheries for direct human consumption, tuna products appear to be relatively less energy-intensive than many aquaculture- and livestock-derived sources of protein. Results of this study provide tuna fishermen, fisheries managers and other stakeholders with a first order estimate of the fuel use and carbon footprint of contemporary tuna fishing vessels, a baseline against which future performance can be measured, and insight into how changing fuel prices may affect different sectors of the tuna fishing fleet.

Table of Contents

Introduction

Beginning with the adoption of steam by fishing vessels in the 1800s and rapidly increasing throughout the 20^{th} century, reliance on fossil fuels has become a defining characteristic of modern industrial fishing fleets (Tyedmers, 2001; 2004). The use of fossil fuels has greatly expanded the range and depth at which fishing can occur (Tyedmers *et al.*, 2005), facilitated new technologies such as industrial freezers and powerful winches, improved the quality and price of fisheries products, and markedly improved the conditions under which fishermen work. However, for many contemporary fisheries, industrial energy inputs now exceed the nutritional energy output of the resulting fish products (Tyedmers, 2004). Moreover, this heavy reliance on fuel renders many fisheries highly vulnerable to fluctuations in oil prices and contributes to a range of environmental concerns, most notably climate change.

The global tuna fishery is one of the largest in the world. Aggregate catches of tuna and associated species (including swordfish (*Xiphias gladius*) and other billfishes) reached a record level of 6.5 million tonnes in 2007 (FAO, 2011a). Landings of skipjack tuna (*Katsuwonus pelamis*) in particular represent the fourth highest catch of any fish species globally, and approximately one third of total landings of tuna and tuna-like species (FAO, 2011a). Fisheries targeting the five most commercially important tunas, including skipjack, yellowfin (*Thunnus albacares*), albacore (*T. alalunga*), bigeye (*T. obesus*), and bluefin (*T. orientalis, T. thynnus, T. maccoyii*), occur in all major oceans of the world, and have collectively grown steadily over the past 60 years (Figure 1). These fisheries vary by the species targeted, the location and depth at which fishing occurs, the fishing gears employed (Figure 2), and the markets targeted for their products. Tuna is a highly valued and widely traded global commodity, representing 8% of fish exports in 2008 (FAO, 2011a). Tuna fisheries also account for a significant portion of the income of many countries through employment, revenues from access fees, and economic spin-off (Pintz, 1989; Barclay & Cartwright, 2007).

The modern tuna fishing industry relies heavily on direct fossil fuel inputs for vessel propulsion, fishing operations, and a range of ancillary activities including onboard freezing, etc. While other activities associated with tuna fishing also entail energy inputs (*e.g.* vessel construction and maintenance, bait provision, *etc.*), previous research suggests that these tend to account for a small fraction of total energy inputs (Rawitscher, 1978; Watanabe & Okubo, 1989; Hospido & Tyedmers, 2005). Tuna fisheries have, in the past, been identified as having a relatively high fuel use intensity (FUI, here defined as litres of fuel burned per landed wet weight tonne) and in some circumstances have been cited as burning drastically greater amounts of fuel than many other fisheries (*e.g.* Nomura, 1980;

Watanabe & Okubo, 1989). To date, however, there has not been a broad, global examination of direct fuel consumption by the world's tuna fishing fleets.

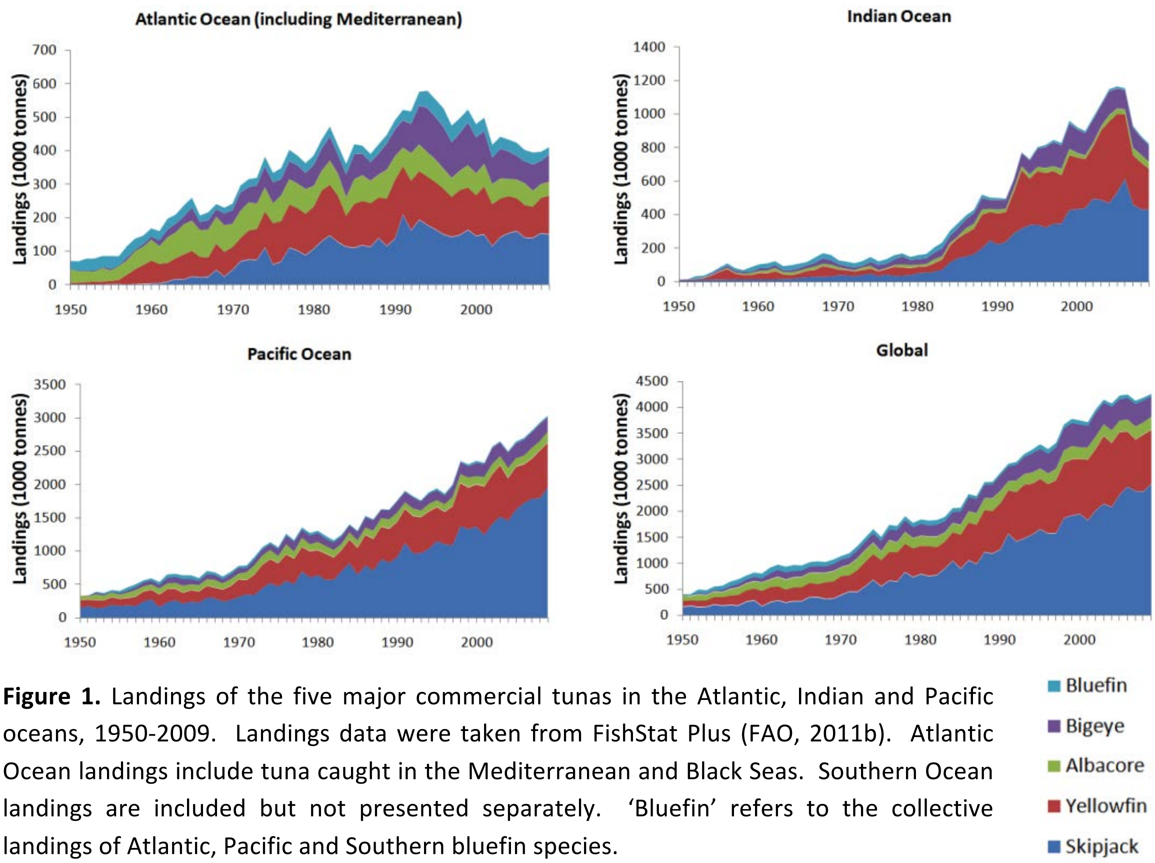


Figure 1. Landings of the five major commercial tunas in the Atlantic, Indian and Pacific oceans, 1950-2009. Landings data were taken from FishStat Plus (FAO, 2011b). Atlantic Ocean landings include tuna caught in the Mediterranean and Black Seas. Southern Ocean landings are included but not presented separately. 'Bluefin' refers to the collective landings of Atlantic, Pacific and Southern bluefin species.

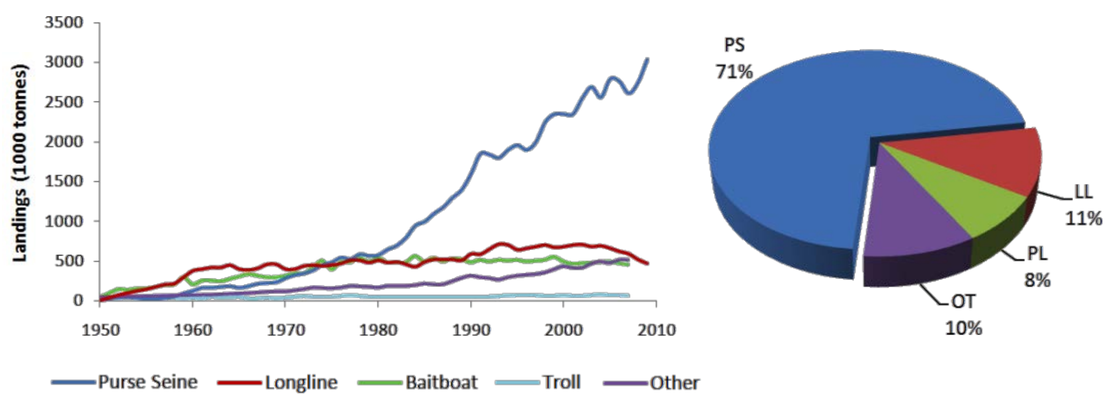


Figure 2. Tuna landings by gear, 1950-2009 (left), and breakdown of 2009 landings by gear (right): purse seine (PS), longline (LL), pole and line (PL) and other gears (OT). Landings from 1950-2007 taken from Miyake and colleagues (2010). Data from 2008-2009 are from Regional Fisheries Management Organizations (note: only purse seine and longline data from 2008-2009 are expressed in the timeline as a result of differences in gear classifications).

Why Measure Fuel Use in Tuna Fisheries?

While the use of fossil fuels has greatly expanded the availability and improved the quality of fisheries products, the fishing industry's dependence on these resources presents a number of challenges. These include concerns related to emissions that result from the combustion of fossil fuels (*e.g*. climate change, ocean acidification, *etc.*) and the economic vulnerability that results from reliance on a finite resource whose value can fluctuate widely.

Environmental Sustainability

Historically, environmental concerns regarding capture fisheries focused on overexploitation of target species and the development of regulatory frameworks to limit overfishing (Ludwig *et al.*, 1993; Thrane *et al.*, 2009). More recently, direct and indirect impacts of fishing activities, such as bycatch, habitat destruction, and effects on related species, have received increased attention.

In an energy-sensitive, carbon-constrained world, the burning of fossil fuels and the release of greenhouse gases (GHGs) have now been added to the list of commonly used sustainability criteria. Terms such as 'carbon footprint' and 'carbon neutral' have entered common usage, and consumers and governments are increasingly sensitive to the energy requirements of products. For fisheries, these issues are closely associated with fishing vessel FUI: typically between 60 and 90% of total life cycle GHG emissions are the direct result of vessel fuel consumption (Ziegler *et al.*, 2003; Hospido & Tyedmers, 2005; Thrane, 2006; Ziegler & Valentinsson, 2008; Parker, 2011; Driscoll *et al.*, *in review*). Vessel fuel consumption typically exceeds the energy use and GHG emissions from processing, packaging and transport of resulting products combined (exceptions include when fresh products are transported by air (Andersen, 2002; Fulton, 2010)).

The overall contribution of fisheries to global GHG emissions appears to be relatively small in absolute terms. According to the 2008 State of World Fisheries and Aquaculture, fisheries "make a minor but significant contribution to… GHG emissions during production operations and the transport, processing and storage of fish" (FAO, 2009). Tyedmers and colleagues (2005) estimated that, globally, marine capture fisheries consumed 42.4 million tonnes of fuel in 2000, or 1.2 % of global oil consumption, and released approximately 134 million tonnes of carbon dioxide (CO_2) into the atmosphere. It is important to note that, while fisheries have been criticized as being "the most energy-intensive food production method in the world" (Wilson, 1999), these broad estimates of global energy use by fisheries (Tyedmers *et al.*, 2005) actually suggest that fish products are, on average, a far more energy-efficient source of protein than many land-based animal production systems. However, because fuel use varies so drastically between fisheries (Tyedmers, 2004; Schau *et al.*, 2009), closer examination is needed in order to understand which fisheries contribute more or less to overall energy use and GHG emissions, and which perform more favourably in relation to other sources of protein.

Economic Sustainability

A number of factors affect the economic viability of tuna fisheries, including market prices, capital investments, labour costs, freight costs (particularly when fresh products need to be transported via air freight), and costs of fuel (Barclay & Cartwright, 2007). Fuel and labour costs have been identified as the major factors influencing the operational costs of tuna fisheries (Miyake *et al.*, 2010). Fuel costs alone have been shown to represent between 30 and 75 per cent of production costs in some cases (Pintz, 1989; Beverly, 1998; Espejo, 2009; Miyake *et al.*, 2010). As the price of fuel has risen in recent years, the contribution of fuel to the total costs of tuna fishing has also increased. The fuel portion of expenditures by Japanese distant water longliners, for example, steadily increased from 2000 to 2007 to the point of representing 30% of expenditures, the largest single contributor ahead of crew costs at 28% (Miyake *et al.*, 2010).

> "If fuel energy becomes as scarce and expensive in the next decades as suggested by a number of independent geologists, then we should expect the most energy-intensive among industrial fisheries to fold"
>
> (Pauly *et al.*, 2003)

In recent years, a steady and significant increase in crude oil prices has not necessarily been matched by an increase in tuna prices (Figure 3). This issue became most evident in 2008, when high fuel costs forced a number of longline tuna-fishing vessels in the Pacific to cease operations because revenues did not exceed the high costs of fishing (AFP, 2010). These vessels from Taiwan, Japan, China and Korea, fishing primarily for bigeye tuna for the Japanese sashimi market, represented approximately 30% of the world's pelagic long-line fishing boats (Kyodo News, 2008). Rapidly rising costs of oil and insufficient revenues threaten both fishermen and the economies and countries where tuna and other fisheries contribute significantly to gross domestic product (Espejo, 2009). In a world in which global oil resources are finite yet demand continues to increase, the trend of rising oil prices can only be expected to continue in the future.

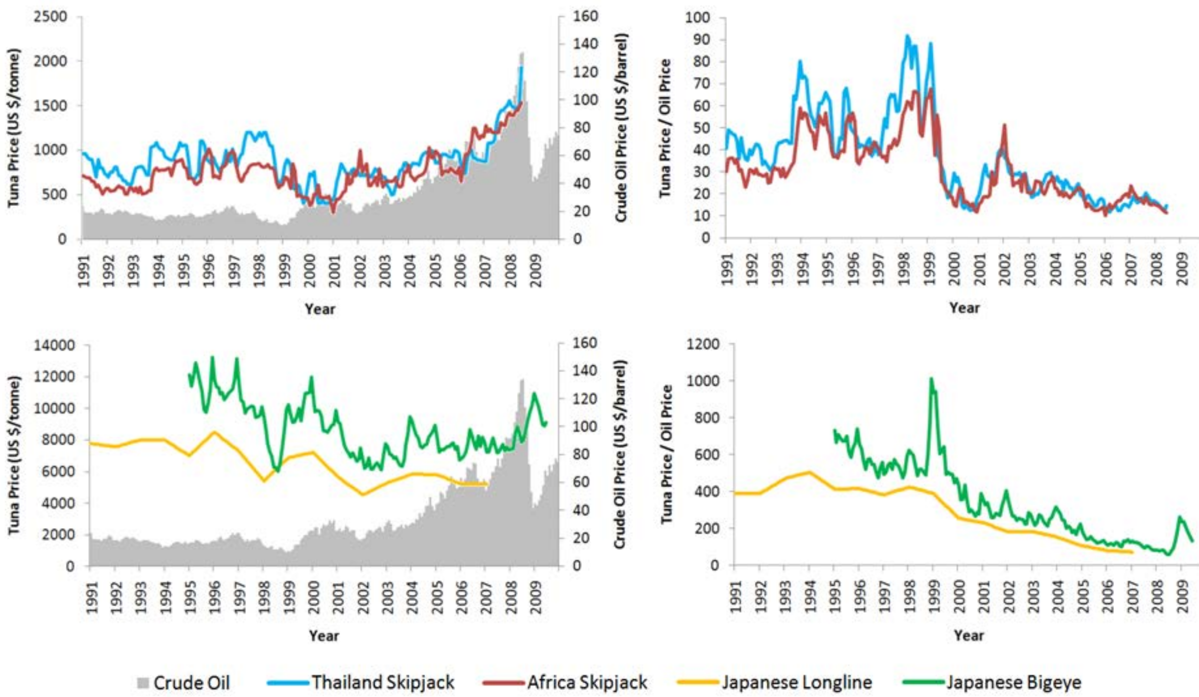


Figure 3. Prices for select tuna products compared to (left side) and as a factor of (right side) global crude oil prices. Reproduced from Miyake *et al.* (2010), OPRT (2010), and FAO (2011a).

Competitive Advantage

A growing number of product labeling schemes have been developed in recent years focused on communicating the relative environmental performance of seafood products (Wessells *et al.*, 2001; Thrane *et al.*, 2009). Recently it has been suggested that assessments and declarations regarding the environmental performance of seafood products should also consider concerns over energy use and GHG emissions (Pelletier & Tyedmers, 2008; Thrane *et al.*, 2009). This argued expansion of sustainability criteria is reflective of the global reality of transitioning into a carbon-constrained world.

Measuring and improving the energy use and associated GHG emissions from fisheries can also provide a competitive advantage, by demonstrating interest on the part of fishermen and fishing companies in improving environmental performance, by actively tracking and demonstrating improvements in performance, and by communicating to consumers any relative environmental benefits in choosing certain products over others. Differences in energy use and emissions exist both between different fisheries and between fishery- and non-fishery protein sources (*e.g.* pork, beef, poultry, soy, *etc.*).

Research Objectives

This document reports results of research undertaken to estimate:

1. average FUI and associated GHG emissions from contemporary tuna fisheries differentiating, where possible, on the basis of species being targeted, fishing gear being deployed and fishery location; and
2. the scale of global fuel consumption and resulting GHG emissions associated with global tuna fisheries.

The research was carried out between August, 2010 and June, 2011 by Dr. Peter Tyedmers and Mr. Robert Parker of the School for Resource and Environmental Studies at Dalhousie University, Canada. The project was supported and facilitated by the International Seafood Sustainability Foundation (ISSF). In addition to the two primary objectives described above, this research also set out to:

- synthesize and report all known data regarding fuel use in tuna fisheries;
- identify trends, if any, in FUI in tuna fisheries through time; and
- contextualize tuna fishing-related fuel use by providing comparisons to other fishery- and non-fishery sources of protein.

Materials and Methods

Contemporary Tuna Fishing Data Collection and Analysis

Data regarding contemporary tuna fishing operations were elicited from industry through the distribution of a brief, focused survey. Potential survey respondents were identified in several ways. First, ISSF partners were asked to identify individuals and companies with direct knowledge of tuna fishing operations who could be approached for data (Appendix A). Second, ISSF partner companies directly engaged in tuna fishing were approached directly for data (Appendix B). Finally, other tuna fishing companies and organizations not directly partnered with ISSF were approached using email addresses available on their website or through personal contacts in the industry.

The survey instrument that was sent out to all identified industry contacts was developed with input from ISSF staff. The resulting survey (Appendix C) elicited a number of vessel- or fleet-specific characteristic and operational details for the 2009 fishing year, including:

- Vessel length, gross registered tonnage, and engine horsepower
- Fishing locations, FAO areas, and EEZ countries
- Primary and secondary gears
- Use of fish aggregating devices (FADs)
- Days on fishing trips and days actively fishing tuna
- Total fuel consumption
- Landings of all tuna and non-tuna species

Surveys and cover letters were distributed by email, and initial attempts, if unsuccessful, were followed up with secondary emails after several weeks. Respondents were asked to return completed surveys either directly to a designated email account set up for the purposes of this study, or to forward them through ISSF or other industry contact persons.

The use of surveys to elicit data from industrial fisheries is associated with a number of challenges (Reid & Squires, 2007). Most prominent is the potential of a low response rate resulting from reluctance on the part of vessel owners or operators to provide company-specific data, time constraints on vessel operators, and/or effort required to access and gather requested information. Additional challenges include possible bias as a result of self-reporting, possible confusion as to what information is being requested, and sample bias as a result of how and to whom the survey is distributed.

Data obtained from returned surveys were aggregated by gear, ocean basin and species. Primary data were compiled in a Microsoft Excel spreadsheet for analysis. Fuel use intensity was calculated specific to each gear, ocean basin and species, and combinations thereof, and weighted by mass of landings (as opposed to number of specimens, nutritional value, or financial value of catch).

Secondary Data Compilation

In addition to collecting primary data from vessels engaged in tuna fisheries in 2009, this study also sought to gather and synthesize pre-existing data on tuna fisheries and fuel use. Data regarding fuel inputs to tuna fisheries have been reported in various peer-reviewed articles, grey literature and academic publications for over 30 years (see for example Rawitscher, 1978). These data have been compiled and recorded in a database on fuel use in fisheries maintained by Peter Tyedmers. For this project, all data regarding fuel inputs, landings by species, and vessel and gear characteristics of fisheries reporting tuna landings were extracted from the database and compiled in a Microsoft Excel spreadsheet, noting the year, gear, locale, primary target species, landings by species, and reported FUI.

Some challenges exist when incorporating data from diverse secondary sources. Original data collection and analysis methods may vary from study to study. For example, estimates of FUI can be derived from reports of actual fuel consumption, by quantities of fuel purchased, or by calculations based on horsepower and fishing effort (see Tyedmers, 2001). As well, some studies may report data corresponding to a single vessel while others may report data representing several vessels or even an entire nation's fleet for a given year. The method of reporting species-specific FUI also varies between studies: Some studies provide FUI measurements for a single species of tuna (*e.g*. skipjack, yellowfin), while others provide FUI measurements for vessels or fleets fishing multiple species, and still others report FUI for broader classifications of target species (*e.g*. "tunas, bonitos and billfishes").

Carbon Footprint and Scaling Up

Estimates of GHG emissions (i.e. carbon footprint) resulting from direct fuel inputs were calculated based on FUI, and reported in kg carbon dioxide-equivalent emissions (CO_2-e) per tonne landed tuna. Given the range in size of vessels engaged in tuna fishing, the fuel burned was assumed to be a mix of marine diesel oil, intermediate fuel oil, and Bunker C fuel oil. Fuel-specific GHG emissions, as well as emissions associated with upstream production of fuel, were converted into CO_2-e using IPCC (2007) characterization factors and employing SimaPro software from PRé Consultants and EcoInvent life cycle databases from the Swiss Centre for Life Cycle Inventories. The resulting life cycle average GHG emission intensity of fuel was 3.12 kg CO_2-e per litre of fuel burned.

Measurements of ocean basin-, gear-, and species-specific FUI and GHG emissions were used to estimate the fuel inputs and carbon footprint of the global tuna fishing fleet. Scaling up of data to the global level was done using total species- and basin-specific reported landings of tuna in 2009 (FAO, 2011b), and six year (2004-09) average species- and basin-specific landings by gear sector obtained from regional fisheries management organizations (RFMOs).

Summary of Data Collection

Primary data collection efforts yielded 12 returned surveys and 11 less formal communications of data (i.e. not returned in survey format). After data quality checks, returned surveys and communications successfully produced 21 data points, representing a total of 199 vessels whose collective activities spanned three oceans, employed four different gears and resulted in landings of approximately 800,000 tonnes of tuna in 2009 (Table 1). Data collection was particularly successful in acquiring data from vessels fishing with purse seine gear (representing >99% of total landings of responding vessels) and vessels fishing in the Pacific Ocean (84% of total landings). Reporting vessels varied by size, engine horsepower, and fishing effort, with purse seine vessels generally being larger, more powerful, and more continuously engaged in fishing than vessels deploying other gears (Table 2).

Table 1. Summary of landings by ocean, gear and species in 2009 of vessels reporting.

Ocean	Gear	# of vessels	Albacore landings (tonnes)	Bigeye landings (tonnes)	Bluefin landings (tonnes)	Skipjack landings (tonnes)	Yellowfin landings (tonnes)	Total landings (tonnes)
Atlantic[a]	PS	9	95	4,069	0	26,987	31,076	62,227
	LL	1	60	0	0	0	0	60
	TR	54	1,446	2	15	1	0	1,464
	PL	44	3,298	5	845	0	0	4,148
Indian	PS	9	109	4,978	0	36,447	20,900	62,434
	LL	1	63	0	0	0	0	63
Pacific	PS	75	10	19,285	0	592,451	57,451	669,197
	LL	6	330	0	0	0	0	330
Total		199	5,411	28,339	860	655,886	109,427	799,923

a. Including Mediterranean

Note: PS = purse seine, LL = longline, TR = troll, PL = pole and line

Table 2. Characteristics of fishing vessels and tuna fishing activities in 2009 of vessels reporting.

Ocean	Gear	# of vessels	Average vessel length (m)[a]	Average GRT (t)[a]	Average main engine HP[a]	Average auxiliary engine HP[a]	Average days actively fishing tuna[a]
Atlantic[b]	PS	9	70.6	1932	3670	1696	297
	LL	1		97			50
	TR	54	22.3	74	314		70
	PL	44	32.8	177	659		94
Indian	PS	9	81.7	2386	4478	2519	289
	LL	1		89			55
Pacific	PS	75	68.9	1632	3805	2071	244
	LL	6		154			56

a. Weighted by number of vessels

b. Including Mediterranean

Note: PS = purse seine, LL = longline, TR = troll, PL = pole and line

Data represented in surveys reported here represent 18.7% of total global reported landings of the major commercial tuna species (Table 3). By percentage of total landings, fisheries targeting skipjack and yellowfin tunas were best represented, with primary data accounting for 25.8% and 10.6%, respectively, of global landings of these species. Geographically, landings reported in survey responses from the Pacific Ocean are best represented, accounting for 22.1% of total reported catches from the Pacific in 2009.

Table 3. Global reported landings of tuna in 2009 and landings reported by respondents in this study.

		Global landings in 2009 (thousand tonnes)[a]	Reported landings in this study (thousand tonnes)	Reported landings in this study (% of global landings)
Atlantic Ocean[b]	Albacore	41,205	4,899	11.9
	Bigeye	81,476	4,076	5.0
	Bluefin	22,183	860	3.9
	Skipjack	150,179	26,988	18.0
	Yellowfin	115,301	31,076	27.0
	Total	**410,344**	**67,899**	**16.5**
Indian Ocean	Albacore	39,003	172	0.4
	Bigeye	100,210	4,978	5.0
	Bluefin	8,222	0	0.0
	Skipjack	430,464	36,447	8.5
	Yellowfin	244,884	20,900	8.5
	Total	**822,783**	**62,497**	**7.6**
Pacific Ocean	Albacore	166,954	340	0.2
	Bigeye	215,696	19,285	8.9
	Bluefin	19,804	0	0.0
	Skipjack	1,958,747	592,451	30.2
	Yellowfin	674,416	57,451	8.9
	Total	**3,035,617**	**687,174**	**22.1**
Global	Albacore	247,162	5,411	2.2
	Bigeye	397,382	28,339	7.1
	Bluefin	50,209	860	1.7
	Skipjack	2,539,390	655,886	25.8
	Yellowfin	1,034,601	109,427	10.6
	Total	**4,268,744**	**799,923**	**18.7**

a. Landings data from FishStat Plus (FAO, 2011b)

b. Including Mediterranean

Fuel Use Intensity of 2009 Tuna Fisheries

Reported fuel consumption by vessels fishing tuna species in 2009 varied by ocean basin, species, and type of gear (Tables 4 and 5). The greatest differences between fisheries are seen when comparing fisheries using purse seine gear to those deploying other gears, and when comparing fisheries harvesting skipjack, yellowfin and bigeye tunas to those fishing albacore and bluefin species. Vessels fishing with purse seine had an average FUI, weighted by landings, of 368 L/t, while longline vessels burned on average 1,069 L/t, and troll and pole and line vessels consumed 1,107 and 1,485 L/t, respectively. The most fuel-efficient fisheries by species were those targeting skipjack (364 L/t) and yellowfin (395 L/t) tuna, while the least efficient fisheries were those targeting albacore (1,303 L/t) and bluefin (1,478 L/t) tunas. Importantly, it is not possible from the data collected to conclusively identify which factors most influence this relationship, as vessels reporting landings of skipjack, yellowfin and bigeye typically deployed purse seine gear exclusively while vessels targeting albacore and bluefin deployed either longline, pole and line or troll gears (Table 1).

Average FUI varied slightly by ocean, with vessels operating in the Pacific burning the least fuel while vessels operating in the Atlantic burned the most. This may be the result of a greater share of reported landings in the Pacific being caught with purse seine gear (Table 1), although when the FUI of purse seine vessels alone is examined, Pacific-based vessels still appear to consume less fuel than their Atlantic and Indian Ocean based counterparts. For example, purse seine fisheries targeting skipjack burned 349 L/t in the Pacific, 445 L/t in the Atlantic, and 459 L/t in the Indian Ocean. Interestingly, this is a reversal of the pattern described by Hospido and Tyedmers (2005), who found tuna purse seiners operating in the Indian Ocean to have the lowest fuel use intensity while tuna purse seiners operating in the Pacific Ocean had the highest in 2003.

Table 4. Average 2009 fuel use intensities of vessels reporting aggregated by ocean, species and gear

	Landings reported (tonnes)	FUI (L/t)
Atlantic Ocean	67,899	513
Indian Ocean	62,497	454
Pacific Ocean	669,527	354
Purse seine	793,858	368
Longline	453	1069
Troll	1,464	1,107
Pole and line	4,148	1,485
Albacore	5,411	1,303
Bigeye	28,339	465
Bluefin	860	1,478
Skipjack	655,886	364
Yellowfin	109,427	395
All tuna	799,923	375

Table 5. Fishery-specific landings and average fuel use intensities of vessels reporting by ocean, species and gear

Ocean	Species	Gear	Landings (tonnes)	FUI (L/t)[a]
Atlantic[b]	Albacore	Purse seine	95	342
		Longline	60	884
		Troll	1,446	1,107
		Pole and line	3,298	1,485
	Bigeye	Purse seine	4,069	439
		Longline		
		Troll	2	1,107
		Pole and line	5	1,485
	Bluefin	Purse seine		
		Longline		
		Troll	15	1,107
		Pole and line	845	1,485
	Skipjack	Purse seine	26,987	445
		Longline		
		Troll	1	1,107
		Pole and line		
	Yellowfin	Purse seine	31,076	423
		Longline		
		Troll		
		Pole and line		
Indian	Albacore	Purse seine	109	301
		Longline	63	903
	Bigeye	Purse seine	4,978	466
		Longline		
	Bluefin	Purse seine		
		Longline		
	Skipjack	Purse seine	36,447	459
		Longline		
	Yellowfin	Purse seine	20,900	442
		Longline		
Pacific	Albacore	Purse seine	10	323
		Longline	330	1,135
	Bigeye	Purse seine	19,285	471
		Longline		
	Bluefin	Purse seine		
		Longline		
	Skipjack	Purse seine	592,451	349
		Longline		
	Yellowfin	Purse seine	57,451	362
		Longline		

a. Weighted by landings
b. Including Mediterranean

Note: Troll and pole and line fishery data were only reported from fisheries based in the Atlantic Ocean

The Role of Fish Aggregating Devices

Eleven respondents reported data from purse seine vessels which took a portion of their catch, ranging from 20% to 78% of total landings, in association with fish aggregating devices (FADs) in 2009. Together, these surveys represent a total of 93 vessels and combined landings of approximately 794,000 tonnes of tuna, of which close to 83% were skipjack. Those vessels relying most heavily on the use of FADs tended to be longer, larger displacement vessels, although there did not appear to be any clear correlation between FAD use and engine horsepower, fishing effort (days actively fishing tuna), total landings, or composition of landings. A positive correlation was found between the use of FADs and FUI: Those vessels reporting to have relied more heavily on FADs to catch tuna generally also reported higher fuel consumption per tonne of tuna landed (Figure 4 – Note FUI values have been suppressed to protect confidentiality of respondents). However, it is impossible from these data to discern whether the use of FADs is the leading factor in the high FUI of those vessels, as FUI was also positively correlated with vessel size, and we are unable to speculate whether the same vessels fishing without FADs would have a higher or lower FUI.

Interestingly, this apparent correlation contradicts an earlier finding related to the impact of FAD use on FUI. Monintja and Mathews (2000) examined the fuel use, bait use and profits of Indonesian pole and line vessels targeting skipjack before and after the implementation of rumpons in the 1980s, and found that the FUI of the vessels studied decreased dramatically (nearly 50%) after rumpons were introduced. This would suggest that it may be other factors (e.g. vessel size, distance to or location of fishing grounds, engine efficiency, etc.), rather than the use of FADs *per se*, that drive the pattern of purse seine FUI results that we have found. Importantly, Monintja and Mathews also found a marked decrease in bait use when rumpons were used, which would also contribute to lower life cycle energy consumption in that fishery.

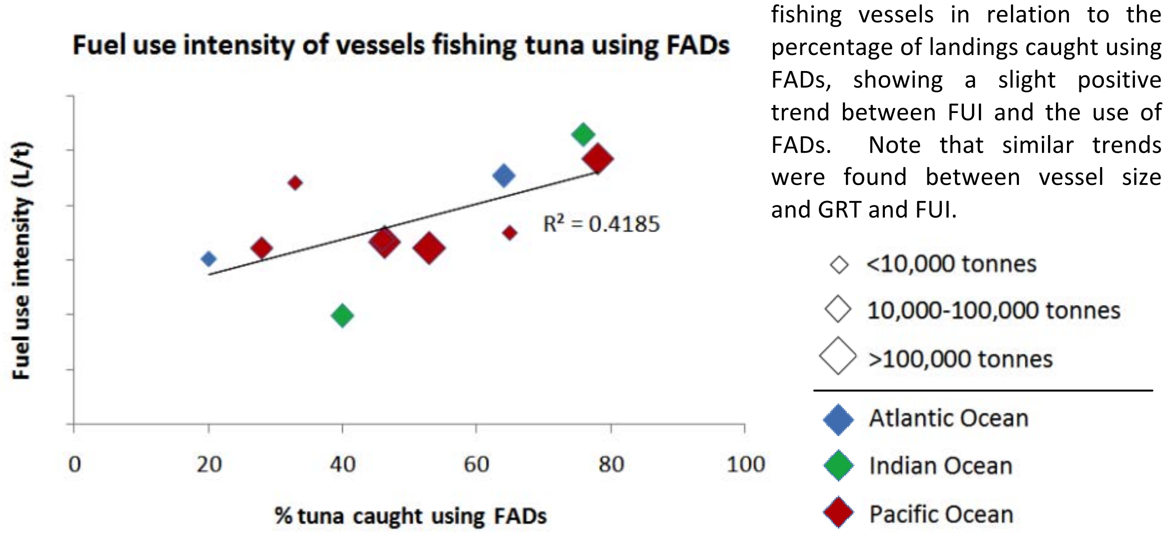


Figure 4. Fuel use intensity of tuna fishing vessels in relation to the percentage of landings caught using FADs, showing a slight positive trend between FUI and the use of FADs. Note that similar trends were found between vessel size and GRT and FUI.

Previous Studies and Trends Over Time

Past studies have reported the FUI of individual vessels as well as entire fleets, ranging from small boats 10-12 metres long catching a few dozen tonnes of tuna (*e.g.* Gallene, 1993; Sokimi & Chapman, 2000; Hazin *et al.*, 2000) to large industrial vessels 60-80 metres long catching upwards of 10,000 tonnes each (*e.g.* Hospido & Tyedmers, 2005). While these studies vary both by methods and by resulting FUI measurements, one clear pattern has emerged: Vessels fishing tuna with longline have historically consumed more fuel per unit wet weight landings than those fishing with purse seine (Table 6). This finding is echoed in the results of the current study. Analysis of primary data collected from purse seiners in the current study clearly falls within the range of FUI values reported in recent publications and datasets (Hospido & Tyedmers, 2005; Wilson & McCoy, 2009; Tyedmers, *unpublished data*) (Figure 5). Interestingly, the range of FUI values previously reported for longline fisheries targeting tunas is much broader, with results of the current study falling towards the lower end of that range (Figure 5).

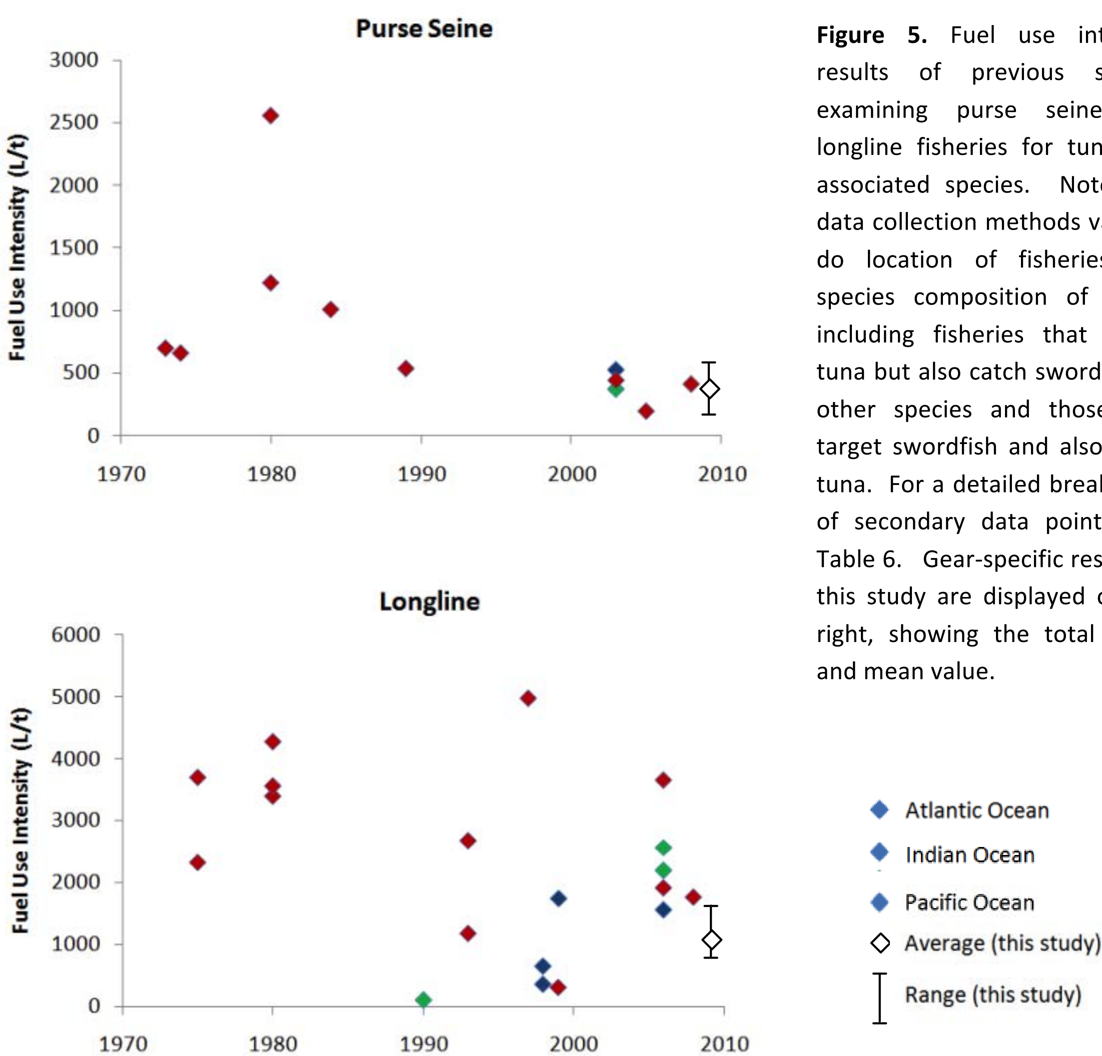


Figure 5. Fuel use intensity results of previous studies examining purse seine and longline fisheries for tuna and associated species. Note that data collection methods vary, as do location of fisheries and species composition of catch, including fisheries that target tuna but also catch swordfish or other species and those that target swordfish and also catch tuna. For a detailed breakdown of secondary data points, see Table 6. Gear-specific results of this study are displayed on the right, showing the total range and mean value.

Table 6. Summary of previous FUI studies of fisheries targeting tuna or landing tuna in association with other species.

Ocean	Gear	Year	Catch (tonnes)	Primary Target	FUI (L/t)	Reference
Pacific	PS	1973		Tuna	697	Rawitscher, 1978
Pacific	PS	1974		Tuna	659	Rawitscher, 1978
Pacific	PS	1980		Yellowfin	2,554	Watanabe & Okubo, 1989
Pacific	PS	1980		Tuna	1,219	Watanabe & Okubo, 1989
Atlantic	PS	2003	23,452	Skipjack / Yellowfin	442	Hospido & Tyedmers, 2005
Indian	PS	2003	29,554	Skipjack / Yellowfin	373	Hospido & Tyedmers, 2005
Pacific	PS	2003	24,994	Skipjack / Yellowfin	527	Hospido & Tyedmers, 2005
Pacific	PS	2005	14,207	Skipjack	195	Tyedmers (*unpublished*)
Pacific	PS	2008		Tuna	412	Wilson & McCoy, 2009
Pacific	T	2005	12	Albacore	1,647	Tyedmers (*unpublished*)
Indian	DN	1988	2	Tunas, bonitos, billfishes	328	Gallene, 1993
Pacific	HL	1975	1,290	Skipjack	1,163	Nomura, 1980
Pacific	HL	1980		Skipjack	1,486	Watanabe & Okubo, 1989
Pacific	HL	1980		Albacore	1,753	Watanabe & Okubo, 1989
Pacific	HL	1980-1984	15,944	Skipjack	1,007	Monintja & Mathews, 2000
Pacific	HL	1985-1989	34,353	Skipjack	535	Monintja & Mathews, 2000
Pacific	LL	1975	259	Tuna	3,704	Nomura, 1980
Pacific	LL	1975	168	Tuna	2,326	Nomura, 1980
Pacific	LL	1980	269	Tuna	4,282	Watanabe & Okubo, 1989
Pacific	LL	1980		Bluefin	3,400	Watanabe & Okubo, 1989
Pacific	LL	1980		Bigeye	3,565	Watanabe & Okubo, 1989
Indian	LL	1990	146	Tunas, bonitos, billfishes	106	Iyer, 1993
Pacific	LL	1993	7,628	Primarily swordfish	2,678	Tyedmers (unpublished)
Pacific	LL	1993	3,627	Primarily Bigeye tuna	1,176	Tyedmers (unpublished)
Pacific	LL	1997	203	Tunas, bonitos, billfishes	4,985	Qu, 1998
Atlantic	LL	1998	115	Primarily swordfish	646	Hazin *et al.*, 2000
Atlantic	LL	1998	28	Primarily swordfish	356	Hazin *et al.*, 2000
Pacific	LL	1999	18	Primarily Albacore	302	Sokimi & Chapman, 2000
Atlantic	LL	1999	1,204	Primarily swordfish	1,740	Tyedmers, 2001
Pacific	LL	2006	390,000	Albacore	1,915	Krampe, 2006
Indian	LL	2006	290,000	Albacore	2,574	Krampe, 2006
Atlantic	LL	2006	476,000	Albacore	1,569	Krampe, 2006
Pacific	LL	2006	408,000	Bluefin / Bigeye	3,660	Krampe, 2006
Indian	LL	2006	680,000	Bluefin / Bigeye	2,196	Krampe, 2006
Atlantic	LL	2006	408,000	Bluefin / Bigeye	3,660	Krampe, 2006
Pacific	LL	2006-2008		Tuna	1,765	Wilson & McCoy, 2009

PS = purse seine, T = trawl, DN = drift nets, HL = hook and line (includes pole and line), LL = longline

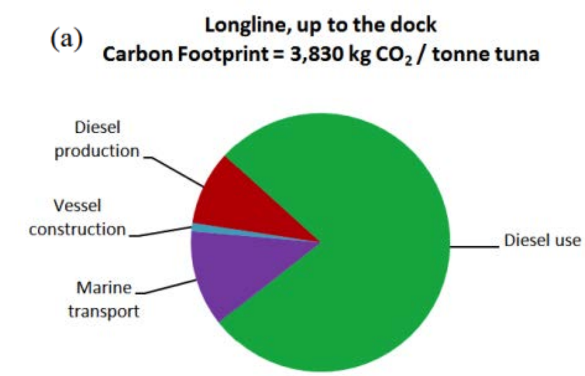
Carbon Footprint

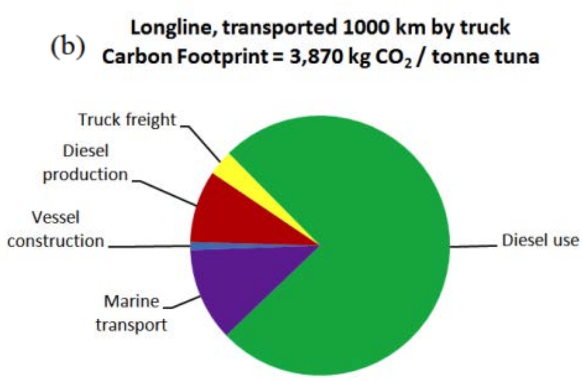
The carbon footprint of a product is an estimate of the total GHGs, expressed in kg CO_2-equivalent emissions, which result from its provision encompassing all underlying activities. The carbon footprint of tuna fisheries, up to the point at which fish are landed, ideally includes all emissions associated with fishing, vessel construction, gear and bait provision, fuel production, refrigeration, and transport of tuna to the dock (see for example, Hospido & Tyedmers, 2005). Because of the diversity of tuna products and complexity of supply chains post-dock, it is more difficult to produce a reliable measure of the complete life cycle emissions of finished tuna products (*i.e.* encompassing processing, packaging, storage, retail, consumer use, disposal) without detailed analyses of specific supply chains, although extended life cycle emissions have been modeled for canned tuna products (Hospido *et al.*, 2006).

Hospido and Tyedmers (2005) examined Spanish purse seine fisheries for skipjack and yellowfin tuna in the Atlantic, Pacific and Indian oceans, and estimated life cycle emissions of GHGs and other substances (*e.g.* sulfur dioxide (SO_2), nitrogen oxides (NO_x), ozone-depleting CFCs, *etc.*). Up to the point at which frozen, unprocessed tuna were landed at Galician ports, fully two thirds of GHG emissions directly resulted from diesel combustion onboard fishing vessels, while ~8% were associated with diesel production, ~2% with vessel construction and maintenance, and ~23% associated with marine transport of frozen tuna to port. The dominant role of direct fuel inputs while fishing is a common finding of life cycle assessments of fishery products; typically between 60 and 90% of life cycle GHG emissions result from direct fuel combustion while fishing (Ziegler *et al.*, 2003; Thrane, 2006; Ziegler & Valentinsson, 2008; Parker, 2011; Driscoll *et al.*, *in review*).

In this research, as we only set out to quantify direct fuel inputs to contemporary tuna fisheries, we are unable to quantify all contributions to the total carbon footprint of tuna fisheries from primary data. However, if we assume a similar proportional breakdown of GHG emissions for vessels reported in this study to that which was found by Hospido & Tyedmers (2005), we can make a coarse estimate of the carbon footprint of landed tuna. Using this approach, we estimate that the total carbon footprint of purse seine-caught tuna in 2009 is approximately 1,530 kg CO_2-e per tonne of tuna landed, 75% of which is directly or indirectly (e.g. extraction, processing, and transport) related to the consumption of fuel by the fishing vessel. In contrast, the total carbon footprint of longline-caught tuna in 2009 can be estimated to be ~3,830 kg CO_2-e per tonne of tuna landed, 87% of which are the direct or indirect result of fuel inputs to fishing vessels (Figure 6). Importantly, this latter estimate does not include inputs associated with bait provision.

An additional consideration, which is important in considering the entire life cycle GHG emissions of tuna products, is the method of transport from the dock to the processor or end market. Frozen or canned tuna, which can be transported by truck or container vessel (at approximately 0.13 and 0.01 kg CO_2-e emissions per tonne-kilometer, respectively, using average European data[1]) will likely have a lower carbon footprint than fresh tuna which needs to be transported by air (at approximately 1.96 kg CO_2-e emissions per tonne-kilometre using average European data[2]). Simply adding this transport stage to our carbon footprint estimates, we see the significant effect it can have on the overall performance of tuna products (Figure 6). While fuel consumption during fishing is surely to remain a significant driver of GHG emissions of canned or frozen tuna products, air freight may in some cases be a critical driver of GHG emissions for sashimi and other fresh tuna products.





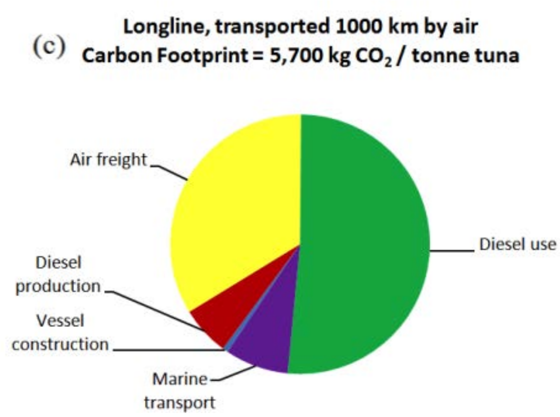


Figure 6. Sources of GHG emissions in the life cycle of longline-caught tuna, (a) up to landing at the dock, (b) landed and transported 1000 km by truck, and (c) landed and transported 1000 km by air freight.

[1] Refers to the GHG emissions resulting from the entire transport life cycle (construction, maintenance and operation of vehicles, construction and maintenance of infrastructure) of >16 tonne trucks, European fleet average, from EcoInvent 2.0; and the entire transport life cycle of transoceanic freight ships, from EcoInvent 2.0

[2] Refers to the GHG emissions resulting from the entire transport life cycle of aircraft freight, from EcoInvent 2.0

Fuel Consumption and Carbon Emissions by the Global Tuna Fishing Fleet

Scaling up our estimates of direct fuel consumption and carbon footprint of tuna fisheries to global landings of the major commercial species of tuna in 2009, we estimate that tuna fishing vessels burned a total of 3 billion litres of fuel in 2009, releasing approximately 9 million tonnes of CO_2-equivalent GHG emissions into the atmosphere in 2009. Vessels fishing tuna with purse seine, while accounting for 64% of global landings of the five principal species, account for only 37% of total fuel use, as a result of the significantly lower FUI of these vessels (Figure 7). Accordingly, fisheries targeting skipjack, which are typically caught with purse seine gear, accounted for 60% of global landings of major commercial tunas in 2009 but only 50% of fuel use. These estimates suggest that the tuna fishery accounts for approximately 7% of Tyedmers and colleagues' (2005) estimate of global fuel use by fisheries (42.4 billion litres in 2000), 0.06% of total global oil consumption (31.2 billion barrels in 2008; EIA, 2011), and 0.02% of total global GHG emissions (44,153 Mt CO_2-e emissions in 2005; WRI, 2009).

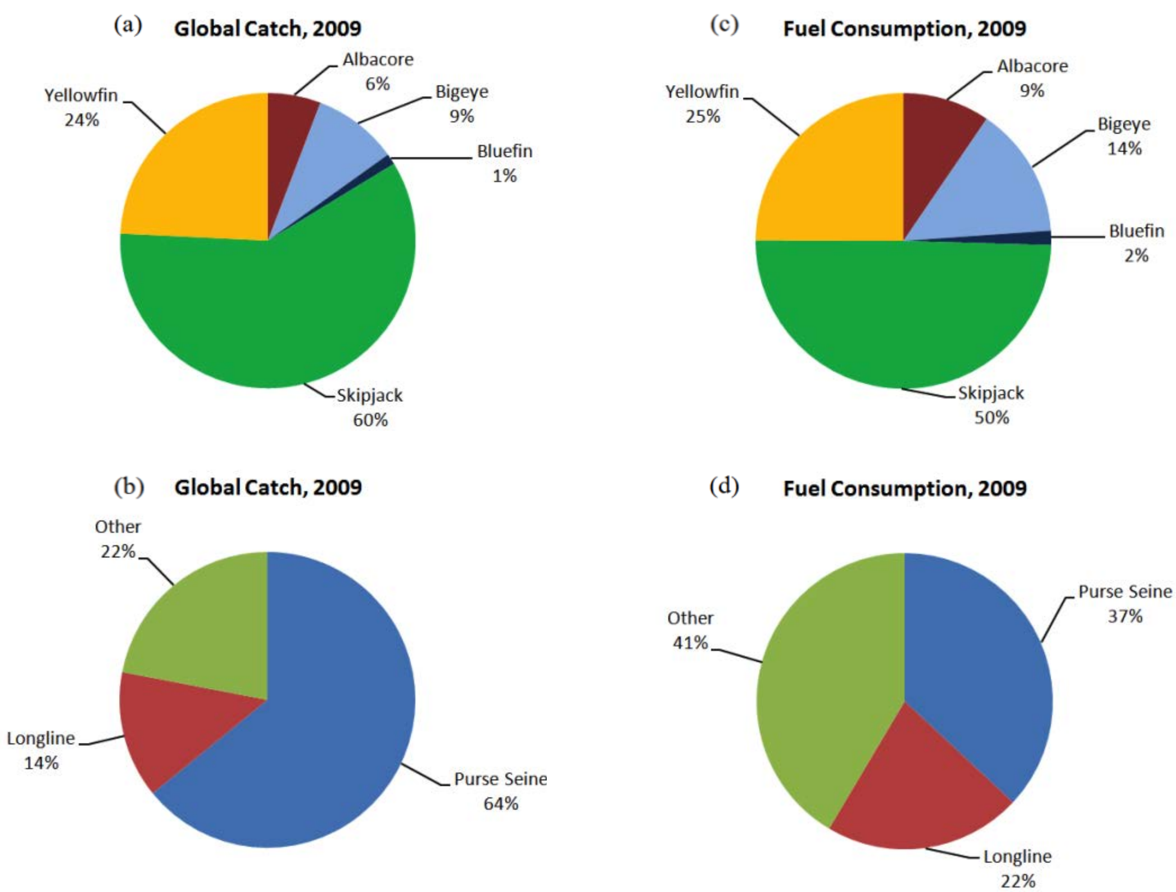


Figure 7. Global landings of major commercial tunas in 2009 broken down by species (a) and gear (b), with corresponding modeled fuel consumption by tuna fishing vessels by species (c) and gear (d). Global catch values by species from FishStat Plus (FAO, 2011b), by gear from RFMO datasets.

Comparison to Other Fisheries

Broad analyses of fuel consumption in fisheries at national or regional scales have been completed by Watanabe and Okubo (1989), Tyedmers (2001, 2004), Thrane (2004) and Schau and colleagues (2009). In addition, numerous fishery-specific analyses have been completed, either focusing entirely on fuel consumption and carbon emissions, or as part of a wider examination of environmental performance (*e.g*. Ziegler *et al.*, 2003; Ziegler & Valentinsson, 2008; Driscoll & Tyedmers, 2010). These analyses have identified a number of patterns in fuel consumption across fisheries. Striking differences exist in fuel inputs to fisheries targeting different species, as well as those using different gears (Table 7).

Tuna fisheries employing purse seine gear have a similar FUI to that of fisheries targeting several other high-valued species for direct human consumption, including cod, haddock and halibut (Table 7). Fuel use intensities associated with many other highly valued species, such as wild-caught salmon, fall somewhere between the FUI of purse-seine caught tuna and tuna caught with more fuel-intensive gears (Table 7). It is important to note that estimates of FUI vary not only between species, gear type and fishing locale, but also over time (Tyedmers, 2004) and between different studies and different research methodologies.

Tuna fisheries cannot be considered the most or least energy-efficient of commercial fisheries, but appear to fall somewhere in the middle. Importantly, the relative performance of tuna when compared to other species is closely associated with the gear used: Purse seine-caught tuna tends to fall in the range of the less energy-intensive fisheries targeting high-value species, while tuna caught with other gears performs better than some fisheries (*e.g*. some lobster and shrimp fisheries), but not as well as many fisheries for species such as cod or salmon.

Table 7. Reported fuel use intensities for select non-tuna fisheries.

	Target species	Fishing Locale	Gear	FUI (L/t)
Pelagic fish	Atlantic herring	NW Atlantic	Purse seine	21[a]
	Mackerel	NE Atlantic		80[b]
	Atl. herring / Atl. mackerel	NE Atlantic	Purse seine	100[c]
	Small pelagics	NE Atlantic		106[d]
	Atlantic herring	NW atlantic	Trawl	118[a]
	Pacific herring	NE pacific	Purse seine	140[e]
	Atl. herring / saithe	NE Atlantic	Danish seine	140[c]
	Atlantic herring	NE Atlantic		140[b]
	Pollack	NE Atlantic		306[d]
	Pacific salmon (var. species)	NE Pacific	Purse seine	360[e]
	Pacific salmon (var. species)	NE Pacific	Gillnet	810[e]
	Pacific salmon (var. species)	NE Pacific	Troll	830[e]
	Swordfish	NW Atlantic	Longline	1,740[c]
Demersal fish	Atlantic cod	NE Atlantic	Gillnet	340[f]
	European hake	NE Atlantic		341[d]
	Atlantic cod	NE Atlantic		412[d]
	Cod / flatfish	NE Atlantic	Danish seine	440[c]
	Atlantic cod	NE Atlantic		470[b]
	Haddock	NE Atlantic		471[d]
	Cod / haddock	NE Atlantic	Longline	490[c]
	Halibut	NE Atlantic		506[d]
	Cod / saithe	NE Atlantic	Trawl	530[c]
	Flatfish	NE Atlantic		560[b]
	European plaice	NE Atlantic		2,165[d]
	Turbot	NE Atlantic		2,447[d]
Shellfish	Blue mussel	NE Atlantic		10[b]
	King crab	NE Atlantic		165[d]
	European lobster	NE Atlantic		306[d]
	Crab (var. species)	NW Atlantic	Trap	330[c]
	Prawns	NE Atlantic		540[b]
	American lobster (Maine)	NW Atlantic	Trap	991[g]
	Northern prawn	NE Atlantic		1,020[b]
	American lobster (Nova Scotia)	NW Atlantic	Trap	1,026[g]
	Norway lobster	NE Atlantic	Trawl	1,030[c]
	Norway lobster	NE Atlantic		1,160[b]
	Northern prawn	NE Atlantic		1,224[d]
	Norway lobster	NE Atlantic		1,224[d]
	Norway lobster	NE Atlantic	Creel	2,156[h]
	Norway lobster	NE Atlantic	Trawl	4,119[h]

[a]Driscoll & Tyedmers, 2010; [b]Thrane, 2004; [c]Tyedmers, 2001; [d]Schau *et al.*, 2009 (FUI allocated by mass); [e]Tyedmers, 2000; [f]Ziegler *et al.*, 2003; [g]Driscoll *et al.*, in review; [h]Ziegler & Valentinsson, 2008 (FUI recalculated using mass allocation)

Comparison to Non-Fishery Sources of Protein

While tuna fisheries appear to have a FUI comparable to many other highly-valued fish species when caught using purse seine, and a higher FUI than many species when caught using other gears, tuna fisheries are much less energy-intensive than many aquaculture- and livestock-derived protein sources. Comparisons on the basis of fuel consumption cannot be made, however, as many land-based operations also rely on other sources of energy (*i.e.* electricity). Broad comparisons of protein sources can be made, however, by calculating a dimensionless ratio of the edible protein energy content of an animal relative to the total industrial energy expended in its production/acquisition: The protein energy return on investment (EROI) ratio (Tyedmers, 2001; Troell *et al.*, 2004; Tyedmers *et al.*, 2005). These analyses generally show, with some exceptions, fishery-derived protein to be less energy-intensive than many aquaculture- and land-based alternatives (Table 8).

Table 8. Edible protein EROI values of select fishery-, aquaculture-, and livestock-derived protein sources.

Product	% EROI
Carp (extensive pond culture)	100-111[a]
Chicken	25[b]
Tuna (purse seine)	**14[c]**
Tilapia (extensive pond culture, Indonesia)	13[a]
Mussel (longline culture, Scandinavia)	10-15[a]
Turkey	10[b]
Carp (Israel)	8.4[a]
Atlantic salmon (intensive net-pen culture, Norway)	8.1[d]
Global fisheries	8.0[e]
Tilapia (intensive net-pen culture in lake, Indonesia)	7.7[f]
Swine	7.1[b]
Dairy (milk)	7.1[b]
Atlantic salmon (intensive net-pen culture, Canada)	6.8[d]
Tilapia (Israel)	6.6[a]
Atlantic salmon (intensive net-pen culture, Chile)	6.4[d]
Tilapia (pond culture, Zimbabwe)	6.0[a]
Tuna (longline)	**5.9[c]**
Tilapia (intensive pond culture, Indonesia)	5.3[f]
Atlantic salmon (intensive net-pen culture, UK)	4.4[d]
Tuna (pole and line)	**4.3[c]**
Catfish (intensive pond culture, US)	4.0[a]
Eggs	2.6[b]
Tilapia (intensive cage culture, Zimbabwe)	2.5[a]
Shrimp (semi-intensive culture, Ecuador)	2.5[a]
Beef cattle	2.5[b]
Lamb	1.8[b]
Sea bass (intensive culture, Thailand)	1.5[a]
Shrimp (intensive culture, Thailand)	1.4[a]

[a]Troell and colleagues, 2004; [b]Pimentel and Pimentel, 2003; [c]Current study; [d]Pelletier and colleagues, 2009; [e]Tyedmers and colleagues, 2005; [f]Pelletier and Tyedmers, 2010

Note – Calculation of EROI for tuna, farmed salmon, and tilapia follows Tyedmers (2001). Assumed 60% edible muscle yield from tuna and salmon, 40% from tilapia. Protein content of muscle assumed to be 20% for salmon and tilapia, 24% for tuna.

Study Limitations

This study sought to gauge the fuel use and carbon emissions of the entire global tuna-fishing fleet and examine how fuel use varies between vessels targeting different species of tuna, those fishing in different locales, and those employing different fishing gears. While successful in gathering and analyzing a significant amount of fuel use data, accounting for approximately 19% of the entire fishery for major commercial species of tuna, there are limitations to the interpretation and application of the results presented here. These limitations can be broadly classified as inherent methodological challenges associated with industry surveys, limits to coverage and representativeness, and exclusion of some issues from the study design.

Methodological Challenges

Several possible sources of error are associated with the methodological style chosen, that is a self-reporting survey distributed through ISSF. First, the sample is likely comprised mostly of companies associated with ISSF, as ISSF was the primary node of survey distribution. While this does not necessarily mean the results are not representative of the wider industry, caution must be exercised when inferring broader representivity. Second, because the study relied on the participation of industry, the data are limited to those companies which could allocate the time and effort required to gather data, and complete and return surveys. Some companies may be cautious of providing data to this kind of survey because they do not know how the data may be used, and those that are willing to respond may not have direct access to data or may not have the time or human resources to devote to acquiring the necessary data (Reid & Squires, 2007). Finally, further error could arise from misreporting of data by respondents due to misunderstanding of the data being requested or error in filling out the survey; this source of error was addressed to the extent possible by following up with companies when data quality issues were recognized, and excluding data that did not meet quality standards.

Coverage and Representativeness.

Data reported in this study are for the year 2009, and are a snapshot of energy performance by tuna-fishing vessels in that year. Importantly, data collection was most successful for tuna-fishing vessels using purse seine and targeting skipjack and yellowfin tuna species. This is potentially a partial result of a sampling bias that results from targeting primarily ISSF-associated companies, as skipjack and yellowfin are targeted for production of canned tuna. Results relating to other gears and to other species should be considered less reliable as a result of the more limited sample sizes involved. Of particular note is the representation of bigeye tuna in this report: Data presented here are from purse seine vessels likely catching small bigeye that swim near the surface with other species, rather than the larger specimens which are typically targeted for use as sashimi and other high end products and which swim at greater depths and are caught primarily with longline gear.

Results also only explored relationships between fuel consumption and a limited set of vessel, catch and effort characteristics of fisheries. As such, it is difficult to draw absolute conclusions as to what the driving force behind higher or lower FUI is, because in many cases FUI correlated with numerous variables. For example, greater reliance on FADs was found to correlate with higher FUI in purse seine fisheries; however, FUI in those cases was also correlated with vessel length and GRT.

Exclusions

This study only examined the fuel consumption of tuna-fishing vessels during the fishing stage of the tuna product life cycle. While more complete life cycle GHG emissions were inferred based on a previous assessment of tuna fisheries (Hospido & Tyedmers, 2005), many life cycle stages were not examined in detail here. These include transport to processors, processing, packaging, storage, wholesaling and retailing, cooking, and disposal. In some cases, these other life cycle stages may constitute significant sources of emissions (e.g. air freight transport). Another important exclusion from analysis was the provision of bait, which may account for an important amount of total energy use and emissions of some tuna fisheries. Additionally, other fisheries-specific environmental concerns were not addressed, including bycatch, ocean pollution, biotic resource use and impacts on related species, and habitat alteration. Rather than providing a measure of overall environmental performance, this study seeks to contribute to the overall understanding of the environmental impacts of tuna fisheries by examining one concern – energy use and carbon footprint – in detail.

Direction for Future Research

Future research efforts should seek to expand on the work done here by examining in more detail those sectors of the industry and aspects of tuna fishing which were not adequately addressed here. In particular, additional effort should be expended to more fully assess the fuel consumption of longline, troll and pole and line gear sectors. Ideally, this effort would also extend to a consideration of energy expended in bait acquisition and use in these fisheries.

As well, because of the increasing usage of FADs and the proportion of the global tuna catch taken using purse seine gear, a more thorough investigation of fuel use by vessels fishing around FADs is needed. Our results suggest that FAD use may not significantly improve FUI – indeed, it may have the opposite effect. However, in order to move beyond this preliminary observation more research should be conducted. This could take the form of either a) a much more robust statistical analysis of finer-scaled operational characteristics of purse seiners fishing under a variety of real world conditions; or b) an experiment-styled study of fishing activities on free swimming schools and FAD associated schools to control for other variables that potentially affect FUI.

Importantly, future analyses of energy use in tuna and other fisheries will almost certainly require comparable and potentially increased levels of support and/or participation of industry. While we were extremely pleased by the level of industry engagement that we experienced in this project, it was largely predicated on the efforts of the ISSF, key members of its staff and partners. Should additional work be undertaken along the lines described above, such a level of industry engagement would need to be replicated or enhanced. Ideally, such participation would be encouraged by governments, RFMOs and other organizations like the ISSF.

Finally, while this study measured and characterized the fuel use and emissions of tuna-fishing vessels, focus was not placed on potential strategies to improve energy or emissions performance. Future work could seek to explore potential strategies to improve performance though improving engine efficiency, reducing distance between port and fishing grounds, limiting pressure on stocks to avoid overcapacity, introducing less energy-intensive fishing gears, and investigating potential opportunities to implement cleaner fuel carriers. Results of the analysis undertaken here would then provide a benchmark against which future performance could be measured to gauge their success.

Acknowledgements

We are extremely grateful to all those in the tuna industry who took time to provide us with data regarding their fishing operations, and to Susan Jackson and Victor Restrepo of the ISSF for all of their efforts on behalf of this project.

APPENDIX A – Introductory letter sent to potential respondents

International Seafood Sustainability Foundation

Re: Important new ISSF research project – carbon footprint of tuna fisheries

The International Seafood Sustainability Foundation has commissioned a research project to quantify fuel inputs and associated global warming contributions (carbon footprint) of various tuna fishing methods currently in use around the world. This research is being undertaken by scientists based at the School for Resource and Environmental Studies at Dalhousie University, Canada under the direction of Dr. Peter Tyedmers. Results of this project will help us better understand the holistic environmental impact associated with their fisheries, the relative impact of the different tuna fishing gear types, and provide a basis upon which the carbon footprint of tuna products could be then estimated and compared to other proteins. Research to date suggests that in many cases, fisheries products compare very favorably with beef and other animal proteins in terms of their carbon footprint.

To succeed, this project will require the assistance of industry. Specifically, the researchers will survey tuna vessel owners and operators over September and October to secure data related to their operations. ISSF will be sending this survey out to you shortly. Please note that the study will aim to cover all of the main tuna fishing methods. Therefore, at this point in the process, we would like you to help us identify other fishing companies who might be willing to participate in the survey. Specifically, please send a list of company names and addresses along with individual contact names, phone numbers and e-mail addresses to the email we have dedicated for the study (tuna.study@gmail.com) , or to Victor Restrepo (VRestrepo@iss-foundation.org) as soon as possible.

All company-specific information provided to the researchers will be kept confidential. Contact lists will not be shared and only aggregated data representing multiple vessels fishing in any given region, utilizing a particular fishing gear type, will be reported in the final study.

Thank you in advance for your assistance with this important project and please contact us or Dr. Peter Tyedmers (peter.tyedmers@dal.ca) if you have any questions.

Sincerely,

Susan Jackson
President

Victor Restrepo
Chair, ISSF Scientific Advisory Committee

International Seafood Sustainability Foundation P.O. Box 11110 McLean, VA 22102
P: 703-226-8102 F: 703-226-8100 info@iss-foundation.org www.ISS-Foundation.org

APPENDIX B – Cover letter accompanying tuna energy use survey

International Seafood Sustainability Foundation

International Seafood Sustainability Foundation

Re: Carbon footprint of tuna fisheries – data request

In September, we announced the start of a new research project to quantify fuel inputs and the associated carbon footprint of various tuna fishing methods currently in use around the world.

We encourage all of our partners who have direct access to tuna fishing data to provide this information to the project and to also urge their contacts in the tuna fishing industry to do the same. To this end, the research team has prepared a short questionnaire to elicit the data required (please see attached). While ideally data would be provided for individual vessels, it is possible to provide aggregate data for vessels fishing in the same region, using the same gear and targeting the same species. Please see the guidance at the top of the questionnaire.

Once you have completed one or more data forms, please forward them directly to the research team via the dedicated e-mail address established for this study (tuna.study@gmail.com) or to Victor Restrepo at ISSF (VRestrepo@iss-foundation.org). Should you have any questions or concerns regarding the questionnaire, please forward them to the same e-mail addresses.

Finally, if you have not yet forwarded contact information for other tuna fishing companies please take the time to do so now. Again, the project team is looking for company names and addresses along with individual contact names, phone numbers and e-mail addresses. Or, you could simply forward this letter and survey to your contacts.

All company-specific information provided to the researchers will be kept confidential. Contact lists will not be shared and only aggregated data representing multiple vessels fishing in a given region, utilizing a particular fishing gear, will be reported in the final study.

Thank you for your continued assistance with this important project and please contact us or Dr. Peter Tyedmers (peter.tyedmers@dal.ca), the project lead if you have any questions.

Sincerely,

Susan Jackson
President

Victor Restrepo
Chair, ISSF Scientific Advisory Committee

International Seafood Sustainability Foundation P.O. Box 11110 McLean, VA 22102
P: 703-226-8101 F: 703-226-8100 SJackson@ISS-Foundation.org www.ISS-Foundation.org

APPENDIX C – Tuna energy use survey

Data regarding individual vessel operations are preferred. However, data representing multiple vessels can be reported on one form **IF** vessels fished in the same region, used the same gear and targeted similar species (e.g. one form could be used to report combined data for say 3 vessels fishing primarily Skipjack Tuna with purse seine in the Indian Ocean). **Please complete and return separate data sheets for individual or groups of vessels using different gear types, fishing in different regions, or targeting different species.** Please indicate the number of vessels this form is reporting on in section 1 below and provide TOTAL fuel purchases, TOTAL landings, TOTAL days at sea, TOTAL fishing days for all vessels represented and average values for all other aspects as appropriate.
Please indicate units used for reporting where appropriate.

1. VESSEL(S) represented: ____ #
Vessel length (or average): ____ m/ft
Vessel GRT (or average): ____ t
Main engine power (or ave): ____ HP/kW
Auxiliary engine power: ____ HP/kW

2. WATERS FISHED in 2009
In 2009 did vessel(s) fish in: ☐ High Seas
(Mark 'X' in one or both) ☐ National EEZ
If EEZ, which countries? ____
FAO Region(s) fished: #'s ____

3. GEAR used in 2009
Primary tuna fishing gear (purse seine, long line, troll, etc.): ____
Secondary fishing gear: ____
What % of catch with secondary gear? ____ %
Did you fish on FADs in 2009? ☐ Yes ☐ No
% of 2009 catch caught using FADs? ____ %

4. EFFORT in 2009
Total days at sea on tuna trips: ____ days
Total days actively fishing tuna: ____ days
Total fuel burned in 2009 by vessel(s): ____ L
Is catch transferred to a carrier vessel? ☐ Yes ☐ No

5. CATCH in 2009 **Please indicate the total live weight mass of *all* tuna and non-tuna landed by all vessels.**

Skipjack tuna	____ t	________	____ t
Yellowfin tuna	____ t	________	____ t
Albacore tuna	____ t	________	____ t
Bigeye tuna	____ t	________	____ t

Can we contact you to clarify data? ☐ Y ☐ N If yes, please include e-mail address: ____
Additional comments (please extend onto a second page if necessary):

We thank you for your participation in this survey. Please send the completed survey to tuna.study@gmail.com
If you have any questions or concerns, please do not hesitate to contact us at the same e-mail address.

References

AFP (Agence France-Presse) (28 May, 2008). High fuel costs could reduce tuna fishing: Industry group. Retrieved from http://afp.google.com/article/ALeqM5gPluTfgvRmF9dLMVV_hEaVHZKCjA

Andersen, O. (2002). Transport of fish from Norway: Energy analysis using industrial ecology as the framework. *Journal of Cleaner Production, 10*(6), 581-588.

Barclay, K., & Cartwright, I. (2007). Governance of tuna industries: The key to economic viability and sustainability in the western and central Pacific Ocean. *Marine Policy, 31*, 348-358.

Beverly, S. (1998). Tuna longline fishing takes a different turn in French Polynesia. SPC Fisheries Newsletter, 85, April/June 1998.

Driscoll, J., & Tyedmers, P. (2010). Fuel use and greenhouse gas emissions implications of fisheries management: The case of the New England herring fishery. *Marine Policy, 34*, 353-359.

Driscoll, J., Boyd, C., & Tyedmers, P. (*in review*). Impacts of an icon: Life cycle assessment of the Maine lobster industry and comparisons to Nova Scotia. *Fisheries Research*.

EIA (Energy Information Administration) (2011). International petroleum (oil) consumption. Data retrieved from http://www.eia.doe.gov/emeu/international/oilconsumption.html

Espejo, E. (18 February, 2009). Tuna in transition. Retrieved from Asian Correspondent, http:// http://asiancorrespondent.com/7168/tuna-in-transition/

FAO (Food and Agriculture Organization of the United Nations) (2009). *The State of World Fisheries and Aquaculture 2008*. Rome: FAO.

FAO (2011a). *The State of World Fisheries and Aquaculture 2010*. Rome: FAO.

FAO (2011b). FishStat Plus: Universal Software for Fishery Statistics Time Series.

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 of Environmental Studies thesis, Dalhousie University.

Gallene, J. (1993). Offshore low energy fishing technology in the Bay of Bengal. In George, V.C., *et al.* (Eds.), Proceedings of the National Workshop on Low Energy Fishing held August 8-9, 1991, Cochin, India.

Hazin, F., Broadhurst, M., & Hazin, H. (2000). Preliminary analysis of the feasibility of transferring new longline technology to small artisanal vessels off northeastern Brazil. *Marine Fisheries Review, 62*(1), 27-34.

Hospido, A., Vasquez, M., Cuevas, A., Feijoo, G., & Moreira, M. (2006). Environmental assessment of canned tuna manufacture with a life-cycle perspective. *Resources, Conservation and Recycling, 47*, 56-72.

Hospido, A., & Tyedmers, P. (2005). Life cycle environmental impacts of Spanish tuna fisheries. *Fisheries Research, 76*(2), 174-186.

IPCC (Intergovernmental Panel on Climate Change) (2007). Climate change – The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

Iyer, H.K. (1993). Economics of operation of fishing vessels for low energy fishing. In George, V.C., *et al.* (Eds.), Proceedings of the National Workshop on Low Energy Fishing held August 8-9, 1991, Cochin, India.
Krampe, P. (2006). Rising fuel prices and its impact on the tuna industry. Tuna 2006 – Ninth Infofish World Tuna Trade Conference, Bangkok, 27 May 2006.
Kyodo News (29 June, 2008). Fuel costs to beach tuna boats. Retrieved from The Japan Times, http://search.japantimes.co.jp/cgi-bin/nb20080629a1.html
Ludwig, D., Hilborn, R., & Walters, C. (1993). Uncertainty, resource exploitation, and conservation: Lessons from history. *Science, 260*, 17-18.
Miyake, M., Guillotreau, P., Sun, C., & Ishimura, G. (2010). *Recent developments in the tuna industry, FAO fisheries technical paper 543*. Rome: FAO.
Monintja, D., & Mathews, C. (2000). The skipjack fishery in Eastern Indonesia: Distinguishing the effects of increasing effort and deploying rumpon FADs on the stock. In J. LeGall, P. Cayre & M. Taquet (Eds.), Pêche thonière et dispositifs de concentration de poisons: colloque Caraïbe-Martinique, Trois-Îlets, 15-19 October 1999.
Nomura, M. (1980). Influence of fish behavior on the use and design of setnets. In J. Bardach, J. Magnuson, R. May, & J. Reinhart (Eds.), Fish behavior and its use in the capture and culture of fishes. Proceedings of the Conference on the Physiological and Behavioral Manipulation of Food Fish as Production and Management Tools, Bellagio, Italy, 3-8 November 1977.
OPRT (Organization for the Promotion of Responsible Tuna Fisheries) (2010). The present and the future of international tuna longline fishing industry. Presentation retrieved from http://www.ffa.int/system/files/PPT_S4_2_Longline_Eiko Ozaki Tue PM.pdf
Parker, R. (2011). Measuring and characterizing the ecological footprint and life cycle environmental costs of Antarctic krill (Euphausia superba) products. Master of Environmental Studies thesis, Dalhousie University.
Pauly, D., Alder, J., Bennett, E., Christensen, V., Tyedmers, P., & Watson, R. (2003). The future for fisheries. *Science, 302*(5649), 1359-1361.
Pelletier, N., & Tyedmers, P. (2008). Life cycle considerations for improving sustainability assessments in seafood awareness campaigns. *Environmental Management, 42*(5), 918-941.
Pelletier, N., & Tyedmers, P. (2010). Life cycle assessment of frozen tilapia fillets from Indonesian lake-based and pond-based intensive aquaculture systems. *Journal of Industrial Ecology, 14*(3), 467-481.
Pelletier, N., Tyedmers, P., Sonesson, Ul., Scholz, A., Ziegler, F., Flysjo, A., … Silverman, H. (2009). Not all salmon are created equal: Life cycle assessment (LCA) of global salmon farming systems. *Environmental Science and Technology, 43*, 8730-8736.
Pimentel, D., & Pimentel, M. (2003). Sustainability of meat-based and plant-based diets and the environment. *American Journal of Clinical Nutrition, 78*(3), 660-663.
Pintz, W. (1989). Fuel use in tuna fishing. Solomon Islands: South Pacific Forum Fisheries Agency.
Qu, Zhi-qiang (1998). Cost-benefit analysis of tuna fishing longliners with deep-freezing capabilities. China Fisheries Economic Research. v. 2. p.32 as translated by Lei Pang, Aug, 2002

Rawitscher, M. (1978). Energy cost of nutrients in the American diet. PhD dissertation, University of Connecticut.

Reid, C., & Squires, D. (2007). Measuring fishing capacity in tuna fisheries: Data envelopment analysis, industry surveys and data collection. In W. H. Bayliff & J. Majkowski (Eds.), Proceedings of the Methodological Workshop on the Management of Tuna Fishing Capacity—Stock Status, Data Envelopment Analysis, Industry Surveys and Management Options, La Jolla, California, USA, 8– 12 May 2006.

Schau, E., Ellingsen, H., Endal, A., & Aanondsen, S. (2009). Energy consumption in the Norwegian fisheries. *Journal of Cleaner Production, 17*, 325-334.

Sokimi, W., & Chapman, L. (2000). Fisheries development section report of sea and fishing trials onboard the Samoan Fisheries Division's new 12.2m "Super Alia", Secretariat of the Pacific Community, Noumea, New Caledonia. Retrieved from http://www.spc.org.nc/coastfish/Sections/Development/Samoa_superalia_web.pdf

Thrane, M. (2004). Energy consumption in the Danish fishery: Identification of key factors. *Journal of Industrial Ecology, 8*(1-2), 223-239.

Thrane, M. (2006). LCA of Danish fish products. *International Journal of Life Cycle Assessment, 11*(1), 66-74.

Thrane, M., Ziegler, F., & Sonesson, U. (2009). Eco-labelling of wild-caught seafood products. *Journal of Cleaner Production, 17*, 416-423.

Troell, M., Tyedmers, P., Kautsky, N., & Ronnback, P. (2004). Aquaculture and energy use. In C. Cleveland (Ed.), E*ncyclopedia of energy, vol. 1* (pp. 97-108). St. Louis, MO: Elsevier.

Tyedmers, P. (2000). *Salmon and sustainability: The biophysical cost of producing salmon through the commercial salmon fishery and the intensive salmon culture industry* (Doctoral dissertation). University of British Columbia.

Tyedmers, P. (2001). Energy consumed by North Atlantic fisheries. In D. Zeller, R. Watson, & D. Pauly (Eds.), Fisheries impacts on North Atlantic ecosystems: Catch, effort, and national/regional datasets. *Fisheries Centre Research Reports, 9*(3), 12-34.

Tyedmers, P. (2004). Fisheries and energy use. In C. Cleveland (Ed.), *Encyclopedia of energy*, (pp. 683-693). New York: Elsevier.

Tyedmers, P., Watson, R., & Pauly, D. (2005). Fueling global fishing fleets. *Ambio, 34*(8), 635-638.

Watanabe, H., & Okubo, M. (1989). Energy input in marine fisheries of Japan. *Bulletin of the Japanese Society of Scientific Fisheries, 53*(9), 1525-1531.

Wessells, C., Cochrane, K., Deere, C., Wallis, P., & Willmann, R. (2001). *Product certification and ecolabelling for fisheries sustainability, FAO fisheries technical paper 422*. Rome: FAO.

Wilson, J. (1999). *Fuel and financial savings for operators of small fishing vessels, FAO fisheries technical paper 383*. Rome: FAO.

Wilson, J., & McCoy, M. (2009). Study of the impact of energy price fluctuations on fisheries in the Pacific, with emphasis on the tuna industry: Energy costs and fishing. Report for the World Bank and the Asian Development Bank.

WRI (World Resources Institute) (2009). World greenhouse gas emissions in 2005. Retrieved from http://pdf.wri.org/working_papers/world_greenhouse_gas_emissions_2005.pdf

Ziegler, F., & Hansson, P. (2003). Emissions from fuel combustion in the Swedish cod fishery. *Journal of Cleaner Production, 11*(3), 303-314.

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. *International Journal of Life Cycle Assessment, 13*, 487-497.