Worldwide Analysis of In-Port Vessel Operational Lubricant Discharges and Leakages

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Abstract

The majority of ocean-going ships operates with oil-lubricated stern tubes and uses lubricating oils in a large number of applications in on-deck machinery and in-water (submerged) machinery. The issue of oil leakage from stern tubes, once considered a part of normal "operational consumption" of oil, has become an issue of concern and is now being treated as oil pollution with full legal consequences. Greater focus on stern tube leakage and the spillage of other types of lubricants used in marine shipping operations have led to a need to evaluate alternatives to these oils and ways to monitor and prevent discharge of lubricants during ship operations in ports and at sea.

This study focuses on marine inputs of lubricant oils within the 4,708 ports and harbours of the world through stern tube leakage and operational discharges in marine shipping. The study results indicate that, overall, the results indicate that each year in over 1.7 million vessel port visits, 4.6 to 28.6 million litres of lubricating oil leaks from stern tubes, and 32.3 million litres of oil is input to marine waters from other operational discharges and leaks.

Total estimated response and damage costs for lubricating oil leaks and operational discharges worldwide based on the probabilities of leakage and operational discharge by vessel type in the 4,708 ports worldwide are estimated to be between US$322 million for conventional lubricating oils.

1 Introduction

The majority of ocean-going ships operates with oil-lubricated stern tubes and uses lubricating oils in a large number of applications in on-deck machinery and in-water (submerged) machinery. The issue of oil-based lubricant discharges into the marine environment has been raised by various studies, most notably GESAMP (2007), which found that 457 million litres of oil enter the oceans a year from regular shipping activities, though this study specifically did not include lubricant discharges during normal ship operations.

Basic calculations presented at International Maritime Organization (IMO) Marine Environment Protection Committee (MEPC) (IMO MEPC, 2008) meetings estimated that 80 million litres of oil-based lubricants are lost at sea annually from stern tubes alone. However there have been as yet no authoritative figures on this or other lubricant pollution to guide delegates and policymakers.

2 Methodology

This study focuses on operational discharges of lubricant oils *within ports and harbors* including discharges that occur during transit within the harbor or port and while moored at docks. The study excludes inputs that occur en-route or on the open ocean, since the monitoring and recording of small discharges at sea is relatively poor making any data analyses on these types of inputs extremely inaccurate.

The study also only includes the leakage, and operational discharge of these lubricants in their application and use in marine shipping (i.e., on the ships themselves as stern tube lubricants, gear lubricants, etc.). It specifically *excludes* accidental spills from vessels (e.g., during a collision) or spills of stored lubricant oils at shore-based facilities or the transport of these lubricants as cargo by tank ships, tank barges, railroad, or tanker truck, or inputs from land-based lubricants using similar machinery, e.g., cranes, as those considered on vessels. Spills are defined as discrete events in which oil is released accidentally, or, occasionally, intentionally through dumping or vandalism, over the course of a relatively short amount of time. Spillage can occur during transfers (e.g. in refilling lubricating oil vesicles), as a result of accidents, such as a collisions, allisions, or groundings, or there is significant structural damage to the vessel.

Two types of lubricating oil inputs are included in the study – stern tube leakages and operational discharges. Inputs are estimated based on port visit data by vessel type for 4,708 ports worldwide, as well as by nation.

Lubricant spills and releases come from a number of different sources on a vessel and it is worthwhile considering the two separately. Focus in the past has always been upon the highly visible spills that take place, with hydraulic fluids being the primary area of concern, as these systems operate at high pressures and high flow rates. They incorporate elastomer seals and flexible hoses that are subject to wear and abrasion, and also to fatigue with continual pressure fluctuations. When a hose bursts, there is a significant amount of oil released onto the deck and then onto the sea, where its presence is very obvious. Similarly leaks from smaller items of deck equipment such as winches and windlasses are very evident. The gearboxes on this equipment are not generally pressurised, but leaking seals on shafts result in gear oil leakage onto the deck and again it makes its way over the side. These occasional spills or leaks are easily evident because they result in a sheen on the water surface – in port, at least.

2.1 Stern Tube Leakage

Stern tube leakage is significant source of lubricant oil inputs to the marine environment. A 2001 study commissioned by the European Commission DG Joint Research Centre (Pavlakis et al., 2001) reported on the extent of ship-based oil pollution in the Mediterranean Sea. The study revealed that routine unauthorized operational discharges of oil created more pollution than accidental spills. Stern tube leakage was identified as a major component of these discharges.

The stern tube of a ship is the connection between the engine and the propeller. Inside the stern tube is the propeller shaft, which is driven by the ship's engine and rotates to turn the propeller round. The stern tube is one of the parts of a ship below the waterline that contains a significant amount of lubricant oil.

Generally, stern tube shaft seals are the only barrier between the oil in the stern tube and the marine environment. A propeller shaft sealing system is designed to prevent the entry of water into the stern tube where it could damage the bearings. The seal is also designed to prevent the leakage of lubricating oil into marine waters. Ideally, in this closed system there should be no leakage to the water.

According to the US Environmental Protection Agency (EPA, 1999), "oil lubricated stern tube seals cannot release oil to the environment under normal ship operations". Some common system design features to prevent releases include :

- Use of multiple sealing rings at both the inboard and outboard stern tube ends;
- Methods to maintain pressure in the stern tube cavity below that of the sea water pressure outside to ensure that in the event of leakage, water will leak in rather than any lubricant leaking out; and
- Positive methods for determining stern tube seal leakage.

Because these seals can become worn over time or damaged by marine debris, particularly rope and fishing lines, oil leakage can occur. Anecdotal and empirical evidence from stern tube lubricant consumption supports this contention. The issue of oil leakage from stern tubes, once considered a part of normal "operational consumption" of oil, has become an issue of concern as it is now being treated as "oil pollution" with the same legal consequences as spills in many jurisdictions (e.g., under the US EPA 2008 National Pollution Discharge Elimination System or "NPDES" regulations implemented in 2009).

There are no completely reliable estimates or methodologies for estimation of stern tube leakage. Clearly, stern tube leakage varies by vessel type, condition, age, and maintenance. Based on on-site inspections, leakage rates are observed to vary with vessel age, especially for stern tubes in older vessels that have been damaged by ropes or fishing nets, and for which maintenance may be a lower priority. There are anecdotal reports of newer vessels rarely requiring stern tube lubricant top-off. Theoretically, with a closed stern tube system there should be no leakage, but observations indicate that there is "rarely a perfectly sealed system" and that there is always some small amount of leakage. It is also not uncommon for older vessels to require 5 – 10 litres per day.

The leakage rate for stern tubes has been widely reported as "6 litres per day" for a vessel of 1,000 DWT, with higher rates for larger vessels and lower rates for smaller vessels (Thorndon, 2004; Carter, 2009; Ahlbom and Duus, 2006; IMO

MEPC, 2008). This reported leakage rate has been explained as being based on the maximum allowable leakage for certification in Lloyd's Registry Class Society Seal Type Approvals for vessels of at least 1,000 deadweight tonnage (DWT), though all classification societies mention leak tests and "zero tolerance" for leakage. According to the Clean Shipping Project of Sweden (Ahlbom and Duus, 2006), there is a "rule of thumb" that up to one percent of the thickness in millimeters of the stern tube seal is an acceptable leakage level when counted as litres per 24-hour period. For a 600 mm seal, this means 6 litres per day. To put these leakage rates into perspective, it is instructive to consider the degree to which such discharges may be noticed by port authorities if not by vessel operators. In the US, the acceptable discharge limit (as per *40 Code of Federal Register (CFR) part 110*) is that quantity that does not create a noticeable sheen (i.e., a rainbow sheen with an average thickness of 0.0003 mm or a silver sheen with an average thickness of 0.0001 mm). One litre of oil would spread to a rainbow sheen covering about three m^2. Six litres would cover 20 m^2. This would likely be noticed by port officials and require a response.

An analysis of data on oil consumption sourced from a lubricant supplier indicates a range of average daily stern tube lubricant consumption rates for different vessels. The average rate across vessel types is 2.6 litres per day, but ranges from less than 1 litre per day to 20 litres per day. The results of the stern tube consumption data analysis are summarized in Table 1.

Table 1. Average Daily Consumption of Stern Tube Lubricants

Vessel Type(s)[1]	**Daily Consumption**
Barge Carrier	20 litres/day
IWW Oil Tanker	11 litres/day
Navy Ships	10 litres/day
General Cargo Ship	7 litres/day
Bulk Carrier; Passenger/Ro-Ro Cargo Ship	6 litres/day
Container Ship; Tender; Live Stock Carrier	5 litres/day
Heavy Load Carrier; Research Vessel; Crude Oil Tanker; Refrigerated Cargo Ship; Chemical Tanker; Container Ro-Ro Cargo Ship; Trawler	4 litres/day
Pusher Tug; Hopper Dredger; Palletised Cargo Ship; Oil Products Tanker; Wood Chips Tanker; Chemical/Oil Products Tanker; Vehicles Carrier; LPG Tanker	3 litres/day
Offshore Supply Ship; Passenger Ferry; Self-Discharging Bulk Carrier; Offshore Tug/Supply Ship; Fish Carrier; Fishing Vessel; Sail Training Ship; Passenger Cruise Ship; Standby Safety Vessel; Cement Carrier; Asphalt/Bitumen Tanker	2 litres/day
Offshore Support Vessel; Bulk/Oil Carrier; LNG Tanker	1 litre/day
Buoy/Lighthouse Vessel; Cable Layer; Crane Ship; Dredger; Fishery Support Vessel; Live Fish Carrier; Motor Hopper; Offshore Processing Ship; Ore Carrier; Passenger/General Cargo Ship; Patrol Vessel; Pipe Layer; Platform; Pollution Control Vessel; Pontoon; Stone Carrier; Trans Shipment Vessel; Water Tanker; Well Stimulation Vessel; Work/Repair Vessel	0 litres/day

[1]Note that vessels such as barge carriers and inland waterway (IWW) oil tankers may be consuming larger amounts of stern tube lubricants due to the degree to which the vessels are submerged.

In the analyses in this report, the value of 6 litres per day is applied as an average *upper limit* and 2.6 litres per day is applied as an *average rate*. Note that there are a number of vessel types for which no stern tube lubricant consumption is reported in this data. This may be a matter of not having samples from these categories, or in some cases there may actually be no leakage.

2.2 Operational Inputs of Deck Machinery

In addition to spills and stern tube leakage, there are "operational inputs" of lubricant oils that occur due to continuous low-level discharges and leakages that occur during normal vessel operations in port. The sources of operational discharges include deck machinery and in-water (submerged) machinery.

Estimates of operational discharges from these operations in this study are based on the "consumption" of oil reported to a lubricant supplier in a five-year collection of data on daily usage of lubricating oils while in port and underway. No other comparable vessel type- and machinery-specific data were available.

Data were adjusted by removing out-lying values that greatly exceeded average values for each vessel and machinery type on the assumption that these would rightly be spills rather than routine operational discharges. These data would tend to underestimate inputs because the voluntary reporting implies that there is a bias towards the more conscientious operators. The assumption is that the oil replaced daily during the port visit represents the amount of leakage in the port. Leakage at sea is not included herein since that oil would have been replaced during the voyage.

Average per-port visit inputs from deck machinery across all vessel types are shown in Table 2. The oil that is used on deck-based machinery can enter the water through rain runoff or during deck washing activities.

Table 2. Average Input of Lubricants from Deck-Based Machinery in Port

Deck Machinery Type	Average Input per Port Visit (litres)
Deck crane gears	0.073
Dredge pump shaft bearings	0.033
Gear-driven mooring winches	0.102
Gear-driven windlasses	0.024
Hose-handling cranes	0.007
Hydraulic system prov cranes	0.022
Hydraulic deck machinery	0.197
Hydraulic windlass mooring winches	0.019
Hydraulic capstans	0.030
Hydraulic cranes	0.096
Hydraulic hatch systems	0.126
Hydraulic mooring winches	0.110
Hydraulic split systems	0.007
Hydraulic system stern ramps	0.027
Miscellaneous hydraulic systems	0.210
Ro-ro hydraulic systems	0.007

Table 2. Average Input of Lubricants from Deck-Based Machinery in Port

Deck Machinery Type	Average Input per Port Visit (litres)
Hydraulic water-tight doors	0.004
Hydraulic windlasses	0.095
Towing winches	0.005
Towing winch gears	0.003
Hydraulic trim tabs	0.025
Tugger winches	0.010
TOTAL	**1.232**

Again, inputs vary by vessel type. Note that not all vessel types have the machinery listed and will thus not have all discharge types listed. Average inputs of lubricating oil from deck-based machinery by vessel type are shown in Table 3. It is estimated that about 10% of the oil enters the water through runoff or washoff. The rest would adhere to the deck and equipment. This may well be an underestimate of input into the water.

Table 3. On-Deck Machinery: Lubricant Consumption per Vessel Port Visit

Vessel Type	Average Consumption per Port Visit (litres)
Bulk Carrier	57.92
Container Ship	57.70
General Cargo	52.14
Chemical Tanker	51.00
Cement Carrier	42.38
Passenger/Ro-Ro	39.96
Ro-Ro Cargo Ship	36.90
Self Disch. Bulk	30.47
Crude Oil Tanker	30.18
Pontoon	25.00
ChemicalTanker	24.79
Dredger	23.60
Refrig. Cargo	21.03
Oil Prod.Tanker	20.12
Tug	20.00
Ore Carrier	19.00
Offshore Tug	13.40
Passenger /Cruise	12.50
Motor Hopper	12.33
Heavy Load Carr.	11.67
Fishing Vessel	11.50
Crane Ship	11.00
Container Ro-Ro	10.87
Vehicles Carrier	10.17
Trans Shipment	9.50
Wood Chip Carr.	9.50
Offshore Supply	8.56
Bulk/Oil Carrier	7.00
Dredger	7.00
Palletised Cargo	7.00
Research Vessel	6.67
Live Fish Carrier	6.00
Passenger/ Cargo	5.25
LPG Tanker	5.05

Table 3. On-Deck Machinery: Lubricant Consumption per Vessel Port Visit

Vessel Type	Average Consumption per Port Visit (litres)
Trawler	3.67
Fishery Support	3.18
Buoy/Lighthouse	3.00
Standby Safety	3.00
Offshore Support	2.50
Platform	1.30
LNG Tanker	1.00
Patrol Vessel	1.00
Pipe Layer	1.00

2.3 Operational Inputs from Submerged Machinery

In addition to inputs from machinery on vessel decks, there are also more direct inputs from in-water (submerged) machinery. There are a number of systems situated below the waterline which require to be lubricated. The main ones to consider are the stern tube bearing, thruster gearboxes, and horizontal stabilisers. All of these have pressurised lubricating oil systems where the pressure is maintained at a higher pressure than the surrounding sea. The reason for this is to ensure that no significant amount of water enters the oil system, where it would compromise the reliability of the unit. The corollary is that any leakage which does take place is from the unit outwards into the sea. When the elastomer seals on propeller shafts or thruster bearings are in good condition this is a small (but continuous) amount of leakage, but any seal wear or damage increases the amount. The lubricant is released well below the waterline into an area of turbulence (the propeller) which means that it is immediately dispersed and no giveaway sheen occurs on the water surface.

Average inputs of lubricant oils from these in-water machinery sources shown in Table 4, and are detailed by vessel type in Table 5. It is assumed that all oil that leaks or discharges from these sources enters the water. Note that not all vessel types have the machinery listed and will thus not have all discharge types listed.

Table 4. Average Port Visit Input of Lubricants from Submerged Machinery

Submerged Machinery Type	Average Input per Port Visit (litres)
Aquamaster – Gears	0.12
Bow Thruster	1.10
Bow Thruster Gears	0.85
CPP System Gears	0.67
Fin Stabiliser Gear	0.13
Gears - Azimuth Thrusters	0.70
Hydraulic Fin Stabiliser	0.24
Hydraulic Thrusters/ CPP	1.14
Hydraulics - Azimuth Thrusters	0.13
Steering Thrusters	0.04
Stern Thruster	2.39
Stern Thruster Gears	0.21

Table 4. Average Port Visit Input of Lubricants from Submerged Machinery

Submerged Machinery Type	Average Input per Port Visit (litres)
Thruster Gears	0.77
Under Water Pump Shaft Bearing	0.03
Waterjet – Hydraulic	0.03
Waterjet Gears	0.03
TOTAL	**8.58**

Table 5. In-Water Machinery: Estimated Lubricant Consumption per Port Visit

Vessel Type	Average Consumption per Port Visit (litres)
Ro-Ro Cargo Ship	28.77
Passenger/Ro-Ro	27.03
General Cargo	26.28
Offshore Tug	25.68
Palletised Cargo	23.00
Barge Carrier	20.00
Offshore Supply	19.09
Oil Prod.Tanker	18.03
Offshore Support	17.08
Passenger /Cruise	17.01
Motor Hopper	17.00
Vehicles Carrier	16.71
Research Vessel	15.39
LPG Tanker	14.74
Tug	13.58
Crane Ship	13.30
Chemical Tanker	12.00
Container Ship	11.92
IWW Oil Tanker	10.50
Naval	10.00
Pollution Control	10.00
Crude Oil Tanker	8.70
Bulk Carrier	7.79
Cement Carrier	7.42
Standby Safety	6.76
Refrig. Cargo	6.63
Self Disch. Bulk	6.51
Trawler	6.50
Dredger	6.33
Patrol Vessel	6.00
Livestock Carrier	5.67
Sail Training Ship	5.60
Heavy Load Carr.	5.00
Tender	5.00
Water Tanker	5.00
Pusher Tug	4.75
Container Ro-Ro	4.50
Offshore Process	4.11
Pipe Layer	4.00
Well Stimulation	4.00
Passenger Ferry	3.33
Stone Carrier	3.33
Fishing Vessel	3.00

Table 5. In-Water Machinery: Estimated Lubricant Consumption per Port Visit

Vessel Type	Average Consumption per Port Visit (litres)
Wood Chip Carr.	2.75
Fishery Support	2.50
Buoy/Lighthouse	2.00
Cable Layer	2.00
Fish Carrier	2.00
Asphalt Tanker	1.50
Work/Repair	1.25
Bulk/Oil Carrier	1.00
LNG Tanker	1.00

For deck machinery-sourced discharges, bulk carriers, and container ships had the highest inputs. Hydraulic deck machinery was the largest source of lubricating oil discharge. For in-water machinery-sourced discharges, ro-ro cargo, ro-ro passenger/cargo, and general cargo ships had the highest input rates. Stern thrusters were the largest input source across all vessel types.

2.4 Estimating Discharge Volumes in Port and Harbour Areas

Discharge volumes were developed based on the types of vessels and lubricant application types (e.g., stern tube vs. gear) based on five years of data of in-port lubricant replacement rates from a lubricant supplier. These rates of discharge were then applied on the basis of five years of reported vessel visits by port for all 4,708 ports worldwide. Stern tube leakage was considered separately from the other types of operational discharges.

3 Results

Table 6 shows lubricant operational discharges for top ten ports and Table 7 shows lubricant inputs for all nations, assuming maximized stern tube leakage rates.

Table 6. Annual Lubricant Input – Top Ten Ports

Country/Territory	Port	Annual Lube Oil Inputs in Ports (litres)		
		Stern Tube	Other Operational	Total
Singapore	**Singapore**	892,234	823,657	1,715,891
Turkey	**Istanbul**	787,990	912,282	1,700,272
Gibraltar	**Gibraltar**	668,309	626,562	1,294,871
Germany	**Brunsbuttel**	480,679	604,036	1,084,715
Netherlands	**Rotterdam**	482,222	562,660	1,044,882
China	**Hong Kong**	509,250	520,885	1,030,135
Korea, Republic of	**Busan**	389,508	410,161	799,669
Belgium	**Antwerp**	263,186	286,689	549,875
China	**Shanghai**	269,707	272,884	542,591
Taiwan	**Kaohsiung**	253,375	241,438	494,813

Table 7. Estimated Annual Lubricant Port Inputs – by Nation

Country/Territory	Annual Lube Oil Inputs in Ports (litres)		
	Stern Tube	Other Operational	Total
Aland	4,186	7,576	11,762
Albania	35,198	55,982	91,180
Algeria	154,453	182,697	337,150
American Samoa	1,891	2,524	4,415
Angola	22,838	36,007	58,845
Antarctica	29	42	71
Antigua and Barbuda	24	34	58
Argentina	118,319	96,599	214,918
Aruba	1,054	991	2,045
Australia	424,549	374,357	798,906
Azerbaijan	96	132	228
Azores	22,906	24,613	47,519
Bahamas	54,652	78,662	133,314
Bahrain	386	335	721
Bangladesh	32,719	33,287	66,006
Barbados	17	18	35
Belgium	494,290	636,438	1,130,728
Belize	7,532	12,476	20,008
Benin	15,816	14,833	30,649
Bermuda	17	13	30
Brazil	509,298	434,230	943,528
British Indian Ocean Territory	95	85	180
Brunei Darussalam	11,870	10,160	22,030
Bulgaria	73,118	87,926	161,044
Cambodia	7,783	7,900	15,683
Cameroon	16,813	17,292	34,105
Canada	251,926	223,916	475,842
Canary Islands	153,127	178,295	331,422
Cape Verde	26,111	37,949	64,060
Cayman Islands	565	439	1,004
Chile	157,739	151,233	308,972
China	1,834,020	1,835,829	3,669,849
Colombia	178,806	145,476	324,282
Comoros	638	811	1,449
Congo	14,539	18,111	32,650
Congo, The DRC	8,341	8,998	17,339
Cook Islands	156	227	383
Costa Rica	37,422	37,190	74,612
Cote D'ivoire	42,318	44,750	87,068
Croatia	60,342	77,028	137,370
Cuba	9,112	8,831	17,943
Cyprus	82,796	116,790	199,586
Czech Republic	65	44	109
Denmark	284,814	371,981	656,795
Djibouti	14,534	15,121	29,655
Dominica	70	83	153
Dominican Republic	47,436	59,467	106,903
East Timor	1,310	1,961	3,271
Ecuador	51,594	40,976	92,570
Egypt	510,736	495,591	1,006,327

Table 7. Estimated Annual Lubricant Port Inputs – by Nation

Country/Territory	Annual Lube Oil Inputs in Ports (litres)		
	Stern Tube	Other Operational	Total
El Salvador	11,158	9,759	20,917
Equatorial Guinea	2,213	2,378	4,591
Eritrea	1,742	2,291	4,033
Estonia	88,001	118,653	206,654
Falkland Islands (Malvinas)	4,928	5,253	10,181
Faroe Islands	7,120	9,769	16,889
Fiji	10,196	12,406	22,602
Finland	344,712	502,486	847,198
France	580,966	757,001	1,337,967
French Guiana	3,522	4,185	7,707
French Polynesia	14,051	21,913	35,964
French Southern Territories	8	10	18
Gabon	11,832	12,227	24,059
Gambia	2,046	2,084	4,130
Georgia	32,152	38,241	70,393
Germany	1,135,122	1,387,392	2,522,514
Ghana	30,413	29,308	59,721
Gibraltar	668,309	626,562	1,294,871
Greece	367,896	485,192	853,088
Greenland	1,810	1,964	3,774
Grenada	378	603	981
Guadeloupe	30,595	48,007	78,602
Guatemala	49,272	54,896	104,168
Guinea	9,656	7,702	17,358
Guinea-Bissau	2,279	2,499	4,778
Guyana	11,788	13,775	25,563
Haiti	12,857	16,465	29,322
Honduras	28,242	36,221	64,463
Hungary	2	1	3
Iceland	17,369	19,320	36,689
India	408,114	375,972	784,086
Indonesia	733,633	753,551	1,487,184
Iran (Islamic Republic Of)	72,899	68,931	141,830
Iraq	17,958	23,662	41,620
Ireland	132,384	177,075	309,459
Isle Of Man	5,377	7,396	12,773
Israel	84,558	96,821	181,379
Italy	1,080,499	1,557,218	2,637,717
Jamaica	38,723	44,550	83,273
Japan	1,824,700	1,855,642	3,680,342
Jordan	22,309	22,819	45,128
Kazakhstan	22	33	55
Kenya	20,990	22,591	43,581
Kiribati	187	261	448
Korea, D.P.R.O.	7,348	7,107	14,455
Korea, Republic Of	1,112,074	1,172,092	2,284,166
Kuwait	25,861	22,568	48,429
Latvia	131,831	168,687	300,518
Lebanon	47,954	57,507	105,461
Liberia	4,127	5,042	9,169
Libyan Arab Jamahiriya	34,616	37,299	71,915

Table 7. Estimated Annual Lubricant Port Inputs – by Nation

Country/Territory	Annual Lube Oil Inputs in Ports (litres)		
	Stern Tube	Other Operational	Total
Lithuania	77,201	102,097	179,298
Madagascar	12,901	15,010	27,911
Madeira	10,772	15,573	26,345
Malaysia	536,675	547,924	1,084,599
Maldives	7,466	9,696	17,162
Malta	98,122	123,804	221,926
Marshall Islands	137	117	254
Martinique	14,645	18,309	32,954
Mauritania	13,688	11,426	25,114
Mauritius	17	14	31
Mayotte	3,323	3,998	7,321
Mexico	189,832	225,750	415,582
Micronesia	408	289	697
Monaco	150	409	559
Montenegro	18,733	24,662	43,395
Morocco	119,592	152,774	272,366
Mozambique	20,807	21,612	42,419
Myanmar (Burma)	9,448	11,892	21,340
Namibia	8,851	9,084	17,935
Netherlands	827,455	1,049,775	1,877,230
Netherlands Antilles	21,868	30,888	52,756
New Caledonia	54	79	133
New Zealand	116,974	116,383	233,357
Nicaragua	5,975	5,348	11,323
Nigeria	61,126	53,779	114,905
Northern Mariana Islands	3,929	4,647	8,576
Norway	714,445	942,344	1,656,789
Oman	58,944	55,228	114,172
Pakistan	48,077	45,333	93,410
Palau	229	350	579
Panama	81,568	83,163	164,731
Papua New Guinea	21,979	25,608	47,587
Paraguay	908	1,245	2,153
Peru	47,326	43,344	90,670
Philippines	105,962	107,189	213,151
Poland	167,298	216,423	383,721
Portugal	165,542	189,983	355,525
Puerto Rico	41,191	59,844	101,035
Qatar	41,987	42,295	84,282
Romania	127,752	151,048	278,800
Russian Federation	667,721	781,387	1,449,108
Saint Kitts and Nevis	1,507	2,307	3,814
Saint Lucia	13,658	18,912	32,570
Saint Vincent/Grenadines	493	838	1,331
Samoa	2,734	3,542	6,276
Sao Tome and Principe	1,668	1,952	3,620
Saudi Arabia	174,690	172,616	347,306
Senegal	24,563	25,628	50,191
Serbia	96	101	197
Seychelles	52	57	109
Sierra Leone	4,499	4,776	9,275

Table 7. Estimated Annual Lubricant Port Inputs – by Nation

Country/Territory	Annual Lube Oil Inputs in Ports (litres)		
	Stern Tube	Other Operational	Total
Singapore	919,848	848,012	1,767,860
Slovakia (Slovak Republic)	202	285	487
Slovenia	33,166	36,201	69,367
Solomon Islands	4,565	4,808	9,373
Somalia	4,613	6,004	10,617
South Africa	160,756	138,898	299,654
Spain	1,091,378	1,428,806	2,520,184
Sri Lanka	74,076	74,795	148,871
St. Helena	191	256	447
St. Pierre And Miquelon	5	10	15
Sudan	18,420	22,807	41,227
Suriname	3,532	3,453	6,985
Svalbard /Jan Mayen Islands	251	344	595
Sweden	463,799	614,482	1,078,281
Syrian Arab Republic	65,014	78,618	143,632
Taiwan	574,504	558,668	1,133,172
Tanzania	38,870	21,372	60,242
Thailand	180,980	178,151	359,131
Togo	16,768	16,324	33,092
Tonga	2,281	2,997	5,278
Trinidad and Tobago	67,478	71,294	138,772
Tunisia	70,656	104,032	174,688
Turkey	1,322,634	1,570,781	2,893,415
Turkmenistan	295	275	570
Turks and Caicos Islands	491	795	1,286
Tuvalu	102	135	237
U.S. Minor Islands	7	9	16
Uganda	2	6	8
Ukraine	212,476	241,303	453,779
United Arab Emirates	312,184	322,042	634,226
United Kingdom	1,443,647	1,967,101	3,410,748
United States	1,400,726	1,363,235	2,763,961
Uruguay	21,302	18,181	39,483
Vanuatu	2,645	3,546	6,191
Venezuela	146,660	140,010	286,670
Viet Nam	75,077	80,908	155,985
Virgin Islands (British)	8,008	15,352	23,360
Virgin Islands (U.S.)	42,018	72,851	114,869
Wallis/ Futuna Islands	4	3	7
Western Sahara	6,031	6,730	12,761
Yemen	47,340	47,153	94,493
TOTAL	**28,593,300**	**32,283,580**	**60,876,880**

Table 8. Estimated Annual Lubricant Port Inputs – Top Ten Nations

Country/Territory	Annual Lube Oil Inputs in Ports (litres)		
	Stern Tube	Other Operational	Total
Japan	1,824,700	1,855,642	3,680,342
China	1,834,020	1,835,829	3,669,849
United Kingdom	1,443,647	1,967,101	3,410,748
Turkey	1,322,634	1,570,781	2,893,415

Country/Territory	Annual Lube Oil Inputs in Ports (litres)		
	Stern Tube	Other Operational	Total
United States	1,400,726	1,363,235	2,763,961
Italy	1,080,499	1,557,218	2,637,717
Germany	1,135,122	1,387,392	2,522,514
Spain	1,091,378	1,428,806	2,520,184
Korea, Republic Of	1,112,074	1,172,092	2,284,166
Netherlands	827,455	1,049,775	1,877,230

The results indicate that each year in over 1.7 million vessel port visits, an estimated 4.6 million to as much as 28.6 million litres of lubricating oil leaks from stern tubes and 32.3 million litres of oil is input to marine waters from other operational discharges and leaks. In total, operational discharges (including stern tube leakage) inputs at least 32.3 million litres to as much as nearly 61 million litres of lubricating oil into marine port waters annually – the equivalent of about one and a half Exxon Valdez-sized spills.

If the same rates of discharge occur at sea as they do in port, the estimated worldwide annual inputs of lubricants to marine waters both in ports and harbours and at sea might be estimated to be about four times the port estimate. This assumes that each vessel spends, on average, three days at sea for every day in port. Total worldwide of lubricants from operational leaks and discharges would then be about 130 million to 244 million litres annually. The results are broken down by vessel type as shown in Table 9. These values are the estimated amount of lubricant discharge in ports based on the average annual number of port visits for each vessel type.

Table 9. Worldwide Lube Leakage in Port by Vessel Type 2004 – 2008

Vessel Type	Annual Port Visits	Operational Leakage Rate (Litres/Port Visit)				Total Per Year (litres)
		Stern Tube	Deck Machinery *	In-Water Machinery**	Total Discharge	
General Cargo	481,819	18.00	5.21	20.28	43.49	**20,954,453**
Container Ship	356,992	18.00	5.77	10.46	34.23	**12,218,944**
Prod Tanker	197,501	18.00	2.01	15.04	35.05	**6,923,200**
Ro-Ro Cargo	172,566	12.00	3.69	24.67	40.36	**6,964,419**
Bulk Carrier	143,765	18.00	5.79	1.93	25.73	**3,698,383**
Crude Tanker	55,665	18.00	3.02	11.00	32.02	**1,782,299**
Vehicle Carrier	49,754	18.00	1.02	17.05	36.07	**1,794,463**
Passenger Ship	42,285	6.00	1.25	15.04	22.29	**942,617**
LPG Tanker	37,625	12.00	0.51	12.18	24.69	**928,863**
Chem Tanker	35,682	18.00	5.10	8.50	31.60	**1,127,551**
Refrig Cargo	30,501	12.00	2.10	3.00	17.10	**521,653**
Tug	19,786	6.00	2.00	10.39	18.39	**363,884**
Offshore Supply	18,671	6.00	0.86	23.21	30.07	**561,411**
Cement Carrier	15,341	12.00	4.24	5.71	21.95	**336,767**
Self-Discharge	11,932	18.00	3.05	5.33	26.38	**314,763**
Fishing Vessel	11,833	6.00	1.15	2.00	9.15	**108,272**
Passenger Ferry	9,120	18.00	0.00	2.00	20.00	**182,400**
LNG Tanker	6,809	18.00	0.10	0.00	18.10	**123,243**
Hopper Dredger	4,939	12.00	2.36	3.33	17.69	**87,386**

Table 9. Worldwide Lube Leakage in Port by Vessel Type 2004 – 2008

Vessel Type	Annual Port Visits	Operational Leakage Rate (Litres/Port Visit)				Total Per Year (litres)
		Stern Tube	Deck Machinery *	In-Water Machinery **	Total Discharge	
Palletized Cargo	4,928	12.00	0.70	20.00	32.70	**161,146**
Pusher Tug	4,321	6.00	0.00	1.50	7.50	**32,408**
Dredger	4,124	6.00	0.70	0.00	6.70	**27,631**
Bitumen Tanker	3,843	12.00	0.00	0.00	12.00	**46,116**
Research Vessel	3,787	6.00	0.67	12.67	19.33	**73,216**
Not Specified	3,608	0.00	0.00	0.00	0.00	**0**
Fish Factory	3,276	12.00	0.60	0.00	12.60	**41,278**
Barge	3,221	6.00	0.00	0.00	6.00	**19,326**
Landing Craft	3,072	0.00	0.70	0.00	0.70	**2,150**
Wood Chips	2,674	18.00	0.95	0.00	18.95	**50,672**
Heavy Load	2,422	18.00	1.17	11.00	30.17	**73,064**
Livestock Carr	2,205	18.00	0.00	1.00	19.00	**41,895**
Edible Oil Tank	2,182	6.00	2.48	8.68	17.16	**37,436**
Ore Carrier	1,796	18.00	1.90	0.00	19.90	**35,740**
Standby Vessel	1,466	0.00	0.30	5.90	6.20	**9,089**
Deck Cargo	1,351	12.00	1.09	2.00	15.09	**20,382**
Yacht	1,290	0.00	0.00	0.00	0.00	**0**
Pontoon	1,159	6.00	2.50	0.00	8.50	**9,852**
Wine Tanker	892	6.00	2.48	8.68	17.16	**15,304**
Motor Hopper	880	6.00	1.23	17.00	24.23	**21,325**
Cable Layer	800	6.00	0.00	2.00	8.00	**6,400**
Limestone Carr	758	18.00	0.00	0.00	18.00	**13,644**
Naval	753	12.00	0.00	0.00	12.00	**9,036**
Crewboat	737	0.00	0.00	0.00	0.00	**0**
Buoy Vessel	673	0.00	0.30	2.00	2.30	**1,548**
Stone Carrier	571	18.00	0.00	3.33	21.33	**12,181**
Patrol Vessel	552	0.00	0.10	6.00	6.10	**3,367**
Other Ships	474	6.00	0.00	0.00	6.00	**2,844**
Training Ship	467	0.00	0.00	3.60	3.60	**1,681**
Water Tanker	458	6.00	0.00	5.00	11.00	**5,038**
Training Ship	430	6.00	0.00	3.60	9.60	**4,128**
Utility Vessel	426	0.00	0.70	0.00	0.70	**298**
Offshore Proc	412	18.00	0.00	4.11	22.11	**9,108**
Ore/Oil Carrier	390	18.00	0.70	0.00	18.70	**7,293**
Waste Vessel	362	6.00	0.00	1.25	7.25	**2,625**
Urea Carrier	327	18.00	2.48	8.68	29.16	**9,534**
Fishing Support	306	6.00	0.32	2.50	8.82	**2,698**
Pollution Control	300	6.00	0.00	10.00	16.00	**4,800**
Supply Vessel	254	6.00	1.34	27.53	34.87	**8,856**
Aggreg Carrier	253	6.00	0.00	0.00	6.00	**1,518**
Juice Tanker	251	18.00	2.48	8.68	29.16	**7,318**
Salvage Ship	218	0.00	0.70	0.00	0.70	**153**
Pipe Layer	213	18.00	0.10	7.00	25.10	**5,346**
Platform	191	12.00	0.13	0.00	12.13	**2,317**
Work Vessel	175	0.00	0.00	1.25	1.25	**219**
Well Vessel	141	12.00	0.00	33.36	45.36	**6,396**
Sludge Tanker	130	18.00	2.48	8.68	29.16	**3,790**
Icebreaker	122	12.00	0.70	0.00	12.70	**1,549**
Crane Ship	100	0.00	1.10	13.30	14.40	**1,440**
Sugar Carrier	81	18.00	2.48	8.68	29.16	**2,362**
Search/ Rescue	79	0.00	0.70	0.00	0.70	**55**

Table 9. Worldwide Lube Leakage in Port by Vessel Type 2004 – 2008

Vessel Type	Annual Port Visits	Operational Leakage Rate (Litres/Port Visit)				Total Per Year (litres)
		Stern Tube	Deck Machinery *	In-Water Machinery**	Total Discharge	
Drilling Ship	75	18.00	1.34	27.53	46.87	**3,515**
Pilot Vessel	60	0.00	0.70	0.00	0.70	**42**
Mooring Vessel	53	0.00	0.70	0.00	0.70	**37**
Powder Carrier	50	6.00	0.00	0.00	6.00	**300**
Alum Carrier	45	18.00	0.00	0.00	18.00	**810**
Seal Catcher	37	0.00	0.37	4.00	4.37	**162**
Molasses Tank	29	6.00	2.48	8.68	17.16	**498**
Tender	27	6.00	0.00	0.00	6.00	**162**
Nuclear Carrier	25	18.00	0.00	0.00	18.00	**450**
Hospital Vessel	24	12.00	0.00	0.00	12.00	**288**
Fish Oil Tanker	23	6.00	2.48	8.68	17.16	**395**
Tank-Cleaning	20	6.00	0.00	1.25	7.25	**145**
Production Test	17	12.00	0.25	23.79	36.04	**613**
Fire Fighting	16	6.00	0.70	0.00	6.70	**107**
Trans-Shipment	9	18.00	0.95	0.00	18.95	**171**
Whale Catcher	4	6.00	0.37	4.00	10.37	**41**
Air Cushion	1	0.00	0.00	0.00	0.00	**0**
Anchor Hoy	1	0.00	0.00	0.00	0.00	**0**
Floating Dock	1	0.00	0.00	0.00	0.00	**0**
Launch	1	0.00	0.70	0.00	0.70	**1**
Tug	1	6.00	0.00	1.50	7.50	**8**
TOTAL	**1,767,006**	---	---	---	---	**60,798,285**

*Assumes 10% oil on deck washes into water through deck sweeping, rinsing, or rain runoff; Includes: deck crane gears, dredge pump shaft bearings, gear-driven mooring winches, gear-driven windlasses, hose-handling cranes, hydraulic system prov cranes, hydraulic deck machinery, hydraulic windlass mooring winches, hydraulic capstans, hydraulic cranes, hydraulic hatch systems, hydraulic mooring winches, hydraulic split systems, hydraulic system stern ramps, miscellaneous hydraulic systems, ro-ro hydraulic systems, hydraulic water-tight doors, hydraulic windlasses, towing winches, towing winch gears, hydraulic trim tabs, and tugger winches.
** Includes: aquamaster gears, bow thrusters, bow thruster gears, CPP system gears, fin stabilizer gears, azimuth thruster gears, hydraulic fin stabilizers, hydraulic CPP thrusters, hydraulic azimuth thrusters, steering thrusters, stern thrusters, stern thruster gears, underwater pump shaft bearings, hydraulic waterjets, and waterjet gears.

3.3 Lubricant Spill Impacts and Cost Damages

Oil pollution impacts from lubricating oils need to be viewed in respect of the properties of the lubricating oils (physical behavior, toxicity, etc.), the volumes involved (large numbers of relatively small-volume inputs), and locations involved.

The impacts of spills of lubricant oils in ports involve a combination of the costs involved in cleaning up the spilled oil, the socio-economic impacts (port closures during cleanup response operations, precautionary water intake closures, fishing impacts, tourism impacts), and environmental damages. Because different oil types vary in their impacts and present different challenges for detection and response due their chemical and physical properties (viscosity, specific gravity, evaporation rate, etc.), they need to be considered separately in any evaluation of spill impacts. Likewise, different oil types exhibit different degrees of toxicity, propensity of adherence to bird feathers and mammal hairs and fur, different residence time in the environment, and different potentials for bioaccumulation, environmental impacts can vary considerably by oil type.

Because conventional mineral-based lubricant oils differ significantly in their properties and hence their impacts from crude oils and many petroleum products (e.g., diesel fuel, heavy fuel oil), the spills of these oils should be evaluated and estimated in that regard. Spills of lubricating oils do not readily evaporate but do physically disperse into the water column and remain in the environment for some time. The environmental impact of lubricating oils is not insignificant (Vazquez-Duhalt, 1989) due to their persistence and the frequent presence of heavy-metal additives that increase their toxicity.

This study estimated the costs and damages associated with the stern tube leakage, and other operational discharges estimated to have occurred worldwide using ERC's Basic Oil Spill Cost Estimation Model (BOSCEM) (Etkin, 2004) and relevant portions of the Oil Spill Response Cost- Effectiveness Analytical Tool (OSRCEAT) (Etkin, 2005), as well as an evaluation of the behavior of these oils in previous spill modeling studies and known characteristics of these oils.

Spills of lubricant oils involve response costs as well as socio-economic and environmental damage costs, but chronic low-volume operational discharges of lubricants are unlikely to result in the types of responses generally applied in spills. For this reason, for the operational discharges and leaks estimated in this study only environmental damage costs are estimated. Socio-economic damages are not included because it would be highly unlikely that there would be claims of damages to resources upon which livelihoods are based, mainly because there would be no general awareness of these operational inputs by potential claimants.

Note that the "environmental damage" costs are estimated based on natural resource damage assessment (NRDA) habitat equivalency analysis methodologies used in the US. These methods involve estimating the costs of rehabilitating, restoring, or recreating the impacted environment. While currently there are no known applications of actual environmental damage assessments outside the US, there is a move to include these types of damage costs in the European Union (based on the EU Environmental Liability Directive). Also, within the IMO Marine Environmental Protection Committee, a working group is addressing the issue of valuation of averted oil spillage with regard to averted environmental damage costs. The actual application of these types of environmental damage costs are unclear at this time, though many experts believe that a methodology similar to the habitat equivalency analysis used in the US will be applied. Note that at this time, however, responsible parties in spills are generally not required to pay these types of damages. In the context of this study, the environmental damage figures are a way to quantify environmental impacts using the best methodologies currently available.

Estimated annual environmental damages from lubricant discharges in ports are shown in Table 10 for the ten nations with the highest damages and in Table 11 for all nations. Per-unit costs were developed for each nation by adjusting the per-unit costs in ERC's Basic Oil Spill Cost Estimation Model (BOSCEM) and relevant portions of ERC's Oil Spill Response Cost Effectiveness Analytical Tool (OSRCEAT) as adjusted by regional and national factors (as in Etkin, 2000) adjusted to 2010 US dollars.

Table 10. Estimated Damage Costs from Lubricant Inputs – Top Ten Nations

Country	Operational Discharges/Stern Tube Leakage (litres)	Total Annual Cost (US$)
Japan	3,680,342	$47,539,066
China	3,669,849	$47,403,528
United States	2,763,961	$30,985,573
Korea, Rep. of	2,284,166	$29,504,627
Singapore	1,767,860	$22,835,490
Indonesia	1,487,184	$19,209,992
Taiwan	1,133,172	$14,637,210
Malaysia	1,084,599	$14,009,791
India	784,086	$10,128,058
United Kingdom	3,410,748	$6,803,072

Table 11. Estimated Damage Costs from Lubricant Inputs by Country

Country/Territory	Operational Discharges and Stern Tube Leakage (litres)	Per Litre Environmental Damage Cost (US $)	Total Annual Cost (US$)
Aland	11,762	$1.99	$23,460
Albania	91,180	$1.99	$181,867
Algeria	337,150	$0.17	$57,528
American Samoa	4,415	$11.21	$49,495
Angola	58,845	$0.17	$10,041
Antarctica	71	$1.99	$142
Antigua/Barbuda	58	$0.16	$9
Argentina	214,918	$0.16	$34,384
Aruba	2,045	$0.16	$327
Australia	798,906	$1.99	$1,593,497
Azerbaijan	228	$1.99	$455
Azores	47,519	$1.99	$94,781
Bahamas	133,314	$1.99	$265,908
Bahrain	721	$0.02	$14
Bangladesh	66,006	$12.92	$852,601
Barbados	35	$0.16	$6
Belgium	1,130,728	$1.99	$2,255,348
Belize	20,008	$0.16	$3,201
Benin	30,649	$0.16	$4,903
Bermuda	30	$1.99	$60
Brazil	943,528	$0.16	$150,951
Brit. Ind. O. Terr.	180	$1.99	$359
Brunei Darussalam	22,030	$0.17	$3,759
Bulgaria	161,044	$1.99	$321,218
Cambodia	15,683	$12.92	$202,578
Cameroon	34,105	$0.17	$5,819
Canada	475,842	$0.72	$344,502
Canary Islands	331,422	$1.99	$661,054
Cape Verde	64,060	$0.17	$10,931

Table 11. Estimated Damage Costs from Lubricant Inputs by Country

Country/Territory	Operational Discharges and Stern Tube Leakage (litres)	Per Litre Environmental Damage Cost (US $)	Total Annual Cost (US$)
Cayman Islands	1,004	$0.16	$161
Chile	308,972	$0.16	$49,431
China	3,669,849	$12.92	$47,403,528
Colombia	324,282	$0.16	$51,881
Comoros	1,449	$0.17	$247
Congo	32,650	$0.17	$5,571
Congo, The DRC	17,339	$0.17	$2,959
Cook Islands	383	$1.99	$764
Costa Rica	74,612	$0.16	$11,937
Cote D'ivoire	87,068	$0.17	$14,856
Croatia	137,370	$1.99	$273,998
Cuba	17,943	$0.16	$2,871
Cyprus	199,586	$1.99	$398,094
Czech Republic	109	$1.99	$217
Denmark	656,795	$1.99	$1,310,042
Djibouti	29,655	$0.17	$5,060
Dominica	153	$0.16	$24
Dominican Rep.	106,903	$0.16	$17,103
East Timor	3,271	$12.92	$42,252
Ecuador	92,570	$0.16	$14,810
Egypt	1,006,327	$0.02	$19,213
El Salvador	20,917	$0.16	$3,346
Equatorial Guinea	4,591	$0.17	$783
Eritrea	4,033	$0.17	$688
Estonia	206,654	$1.99	$412,192
Falkland I. (Malv.)	10,181	$0.16	$1,629
Faroe Islands	16,889	$0.16	$2,702
Fiji	22,602	$12.92	$291,951
Finland	847,198	$1.99	$1,689,820
France	1,337,967	$1.99	$2,668,707
French Guiana	7,707	$0.17	$1,315
French Polynesia	35,964	$12.92	$464,548
French South.Terr.	18	$0.16	$3
Gabon	24,059	$0.17	$4,105
Gambia	4,130	$0.17	$705
Georgia	70,393	$1.99	$140,406
Germany	2,522,514	$1.99	$5,031,402
Ghana	59,721	$0.17	$10,190
Gibraltar	1,294,871	$1.99	$2,582,747
Greece	853,088	$1.99	$1,701,568
Greenland	3,774	$1.99	$7,528
Grenada	981	$0.16	$157
Guadeloupe	78,602	$0.16	$12,575
Guatemala	104,168	$0.16	$16,665
Guinea	17,358	$0.17	$2,962
Guinea-Bissau	4,778	$0.17	$815
Guyana	25,563	$0.16	$4,090
Haiti	29,322	$0.16	$4,691
Honduras	64,463	$0.16	$10,313
Hungary	3	$1.99	$6

Table 11. Estimated Damage Costs from Lubricant Inputs by Country

Country/Territory	Operational Discharges and Stern Tube Leakage (litres)	Per Litre Environmental Damage Cost (US $)	Total Annual Cost (US$)
Iceland	36,689	$1.99	$73,180
India	784,086	$12.92	$10,128,058
Indonesia	1,487,184	$12.92	$19,209,992
Iran	141,830	$0.02	$2,708
Iraq	41,620	$0.02	$795
Ireland	309,459	$1.99	$617,246
Isle Of Man	12,773	$1.99	$25,477
Israel	181,379	$0.02	$3,463
Italy	2,637,717	$1.99	$5,261,186
Jamaica	83,273	$0.16	$13,323
Japan	3,680,342	$12.92	$47,539,066
Jordan	45,128	$0.02	$862
Kazakhstan	55	$1.99	$110
Kenya	43,581	$0.17	$7,436
Kiribati	448	$0.17	$76
Korea, D.P.R.O.	14,455	$12.92	$186,716
Korea, Republic Of	2,284,166	$12.92	$29,504,627
Kuwait	48,429	$0.02	$925
Latvia	300,518	$1.99	$599,413
Lebanon	105,461	$0.02	$2,014
Liberia	9,169	$0.17	$1,565
Libyan Arab Jama.	71,915	$0.17	$12,271
Lithuania	179,298	$1.99	$357,627
Madagascar	27,911	$0.17	$4,762
Madeira	26,345	$1.99	$52,548
Malaysia	1,084,599	$12.92	$14,009,791
Maldives	17,162	$0.17	$2,928
Malta	221,926	$1.99	$442,653
Marshall Islands	254	$0.16	$41
Martinique	32,954	$0.16	$5,272
Mauritania	25,114	$0.17	$4,285
Mauritius	31	$0.17	$5
Mayotte	7,321	$12.92	$94,566
Mexico	415,582	$0.16	$66,487
Micronesia	697	$12.92	$9,003
Monaco	559	$1.99	$1,115
Montenegro	43,395	$1.99	$86,556
Morocco	272,366	$0.17	$46,474
Mozambique	42,419	$0.17	$7,238
Myanmar (Burma)	21,340	$12.92	$275,649
Namibia	17,935	$0.17	$3,060
Netherlands	1,877,230	$1.99	$3,744,320
Neth. Antilles	52,756	$12.92	$681,451
New Caledonia	133	$12.92	$1,718
New Zealand	233,357	$1.99	$465,453
Nicaragua	11,323	$0.16	$1,812
Nigeria	114,905	$0.17	$19,606
N. Mariana I.	8,576	$11.21	$96,142
Norway	1,656,789	$1.99	$3,304,628
Oman	114,172	$0.02	$2,180

Table 11. Estimated Damage Costs from Lubricant Inputs by Country

Country/Territory	Operational Discharges and Stern Tube Leakage (litres)	Per Litre Environmental Damage Cost (US $)	Total Annual Cost (US$)
Pakistan	93,410	$12.92	$1,206,579
Palau	579	$12.92	$7,479
Panama	164,731	$0.16	$26,355
Papua New Guinea	47,587	$0.17	$8,120
Paraguay	2,153	$0.16	$344
Peru	90,670	$0.16	$14,506
Philippines	213,151	$12.92	$2,753,277
Poland	383,721	$1.99	$765,369
Portugal	355,525	$1.99	$709,130
Puerto Rico	101,035	$11.21	$1,132,660
Qatar	84,282	$0.02	$1,609
Romania	278,800	$1.99	$556,094
Russian Federation	1,449,108	$1.99	$2,890,388
Saint Kitts/ Nevis	3,814	$0.16	$610
Saint Lucia	32,570	$0.16	$5,211
St. Vincent/Gren.	1,331	$0.16	$213
Samoa	6,276	$11.21	$70,358
Sao Tome/Principe	3,620	$0.16	$579
Saudi Arabia	347,306	$0.02	$6,631
Senegal	50,191	$0.17	$8,564
Serbia	197	$1.99	$393
Seychelles	109	$0.17	$19
Sierra Leone	9,275	$0.17	$1,583
Singapore	1,767,860	$12.92	$22,835,490
Slovakia	487	$1.99	$971
Slovenia	69,367	$1.99	$138,359
Solomon Islands	9,373	$12.92	$121,071
Somalia	10,617	$0.17	$1,812
South Africa	299,654	$0.17	$51,130
Spain	2,520,184	$1.99	$5,026,755
Sri Lanka	148,871	$12.92	$1,922,970
St. Helena	447	$1.99	$892
St. Pierre/Miquel.	15	$1.99	$30
Sudan	41,227	$0.17	$7,035
Suriname	6,985	$0.16	$1,118
Svalbard/Jan May.	595	$1.99	$1,187
Sweden	1,078,281	$1.99	$2,150,737
Syrian Arab Rep.	143,632	$0.02	$2,742
Taiwan	1,133,172	$12.92	$14,637,210
Tanzania	60,242	$0.17	$10,279
Thailand	359,131	$12.92	$4,638,904
Togo	33,092	$0.17	$5,646
Tonga	5,278	$0.17	$901
Trinidad/Tobago	138,772	$0.16	$22,202
Tunisia	174,688	$0.17	$29,807
Turkey	2,893,415	$1.99	$5,771,201
Turkmenistan	570	$1.99	$1,137
Turks/Caicos I.	1,286	$12.92	$16,611
Tuvalu	237	$12.92	$3,061
US Minor Islands	16	$11.21	$179

Table 11. Estimated Damage Costs from Lubricant Inputs by Country

Country/Territory	Operational Discharges and Stern Tube Leakage (litres)	Per Litre Environmental Damage Cost (US $)	Total Annual Cost (US$)
Uganda	8	$0.17	$1
Ukraine	453,779	$1.99	$905,107
United Arab Emir.	634,226	$0.02	$12,109
United Kingdom	3,410,748	$1.99	$6,803,072
United States	2,763,961	$11.21	$30,985,573
Uruguay	39,483	$0.16	$6,317
Vanuatu	6,191	$0.17	$1,056
Venezuela	286,670	$12.92	$3,702,923
Viet Nam	155,985	$12.92	$2,014,862
Virgin I. (UK)	23,360	$1.99	$46,594
Virgin Islands (US)	114,869	$11.21	$1,287,747
Wallis/Futuna Isl.	7	$12.92	$90
Western Sahara	12,761	$0.17	$2,177
Yemen	94,493	$0.02	$1,804
TOTAL	**60,876,883**		**$322,135,640**

Total estimated costs for lubricating oil operational leak and discharge worldwide based on the probabilities of operational discharges by vessel type in the 4,708 ports worldwide range are estimated to be US$322 million annually.

3.4 Future Changes

The estimated damages are based on current shipping rates (i.e., vessel port visits) and practices. Future oil inputs, and thus damages, will be determined by changes in shipping rates, as well as the implementation of spill and operational leakage and discharge prevention measures and practices.

On the other hand, it is also likely that there may be significant changes in practices that will result in reductions in operational oil inputs. The fact that there has been more public and industry awareness about operational inputs of lubricating oils may lead to more voluntary and regulatory changes in the usage of these lubricants. While operational discharges and leakages of lubricating oil as discussed in this report were not included in the two most significant international studies of oil inputs into the marine environment in recent years (National Research Council, 2003; GESAMP, 2007), there is evidence that there has been an increasing trend to recognize these inputs as greater than spillage-related inputs in international arenas. The issue is being considered by the IMO Marine Environment Protection Committee and the European Commission (Pavlakis et al., 2001). The development of Marine Protected Areas (MPAs) also may lead to tougher restrictions and more conscientious operations in these waters.

In the US, the recent implementation of an Environmental Protection Agency (EPA) regulation that requires all commercial and non-recreational vessels of 79 feet (24 metres) to have general permits under the National Pollution Discharge Elimination System (NPDES) for all operational discharges of any pollutant in US waters will include discharges of lubricating oils from stern tubes, deck-based machinery, and submerged machinery.

Since a certain proportion of lubricant lost to the sea comes from mechanical failure, more regular inspections of equipment by port authorities, in addition to modernization of fleets, would also reduce the problem.

There are also a growing number of alternatives to conventional lubricating oil usage with the supply of bio-based lubricating oils for vessels designed to meet the higher environmental standards for lubricants of the North Sea offshore oil and gas industries. Newly-developed non-oil-based bio-lubricants are significantly less toxic and 100% more biodegradable than conventional mineral-based lubricating oils, but are not yet widely used. There have also been significant advances through alternative engineering designs for stern tubes that eliminate or reduce the amount of lubricating oil in use, such as seawater-lubricated propeller shaft bearings (e.g., Thorndon, 2004; Carter, 2009).

4 Discussion

This study focuses on marine inputs of lubricant oils within the 4,708 ports and harbors of the world through spillage, stern tube leakage, and operational discharges in marine shipping. Overall, the results indicate that each year in over 1.7 million vessel port visits, an estimated 4.6 to 28.6 million litres of lubricating oil leaks from stern tubes, and 32.3 million litres of oil from other operational discharges and leaks. Total annual inputs of lubricating oil worldwide from stern tube leakage and other operational discharges into port waters is estimated to be between 37 million to nearly 61 million litres.

This analysis focuses on discharges in and near ports and harbours and does not specifically estimate the amount of lubricating oil that is discharged in shipping lanes and on the open sea during transit. The rate of discharge during transit may, however, be inferred from the rate at which vessels discharge while in port. Since vessels generally spend more time in transit than in port, the actual level of discharge worldwide may be several times what is estimated for ports and harbours. Thus, the estimate for ports and harbours represents a very conservative estimate of the global lubricant pollution problem.

Assuming that the higher estimate of stern tube leakage is representative of the inputs that may occur in port as well as in transit, the total estimated input of lubricating oil from leakage and operational discharges represents nearly 61 million litres annually worldwide. Putting this volume into perspective with other coastal and marine-based sources of oil pollution, this represents about 10% above the total oil inputs into marine waters estimated in the 2003 NRC Oil in the Sea study (Figure 1).

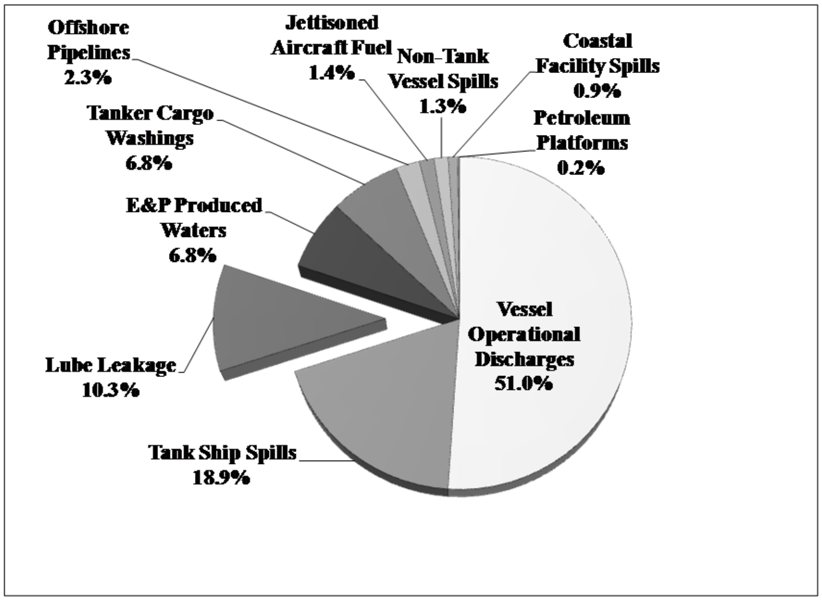

Figure 1. Annual Oil Inputs into the Marine Environment (based on NRC, 2003)

Atmospheric deposition from vessel operations and land-based runoff are not included in this analysis. Note that the category of vessel operational discharges includes MARPOL-permitted discharges at sea but do not include lubricant leakage. Lubricant *spills* are included under tank ship spills and non-tank vessel spills.

Total estimated costs for lubricating oil operational leak and discharge worldwide based on the probabilities of operational discharges by vessel type in the 4,708 ports worldwide range are estimated to be US$322 million annually.

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