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Effective pollution control begins with accurate information concerning the economic sector(s) being managed. For example, a preliminary requirement for controlling air pollution is the availability of information and statistics regarding economic activities—in this case shipping movements and associated fuel consumption—that are generating atmospheric emissions. By combining relevant data on the shipping sector with so-called ‘emissions factors,’ estimates can be made of the levels of contaminants generated and emitted within defined geographic areas. The resulting emissions inventory can then be used—along with information on transport and deposition—to consider damages caused by the emissions and the costs and benefits of their control.

In addition to serving as the basis for an accurate emissions inventory, information about the maritime transport sector can provide additional insight needed to assess policy options aimed at cost-effective control of ship atmospheric emissions. Relevant issues include, inter alia, the nature of the bunker fuel business and the functioning of systems of port fees.

The overall aim of this appendix is therefore to provide adequate baseline information concerning Europe’s maritime transport sector in support of a subsequent evaluation of potential EU-wide policy approaches to the problem of ship atmospheric emissions of SO\(_2\) and NO\(_X\)—the latter evaluation to be presented in Appendices 6 and 7 below. In doing so, the present appendix touches on a broad range of issues, each of which, however, is held to be of direct relevance to the policy issue at hand.

The appendix consists of three main sections. Section 1 looks at the levels and relevant characteristics of shipping traffic in European marine areas,\(^1\) based on data compiled for the present study. Section 2 looks at various issues related to bunker fuels, including sales levels, fuel types, prices and emission factors. Both sections 1 and 2 present relevant data from various emissions studies done to date.\(^2\)

Section 3 presents a relatively simple but effective methodology for estimating energy use and emissions, based on an approach suggested by Corbett et al (1999), but not previously attempted at a regional level. This approach begins with global SO\(_2\) and NO\(_X\) shipping emissions estimates and attempts to apportion these to relevant European marine areas, based on the geographic locations and numbers of ship observations included in the Comprehensive Ocean Atmosphere Data Set (COADS). It will be shown that this ‘top-down’ method, relying on existing data sources, gives results which correspond sufficiently closely with those of more detailed ‘bottom-up’ approaches to be of value. In addition, the method allows comprehensive and inter-comparable coverage of each of the marine areas under study, which was not possible using existing studies.

In discussing emissions, the focus of the present appendix is on methods for determining their ‘absolute’ levels. The question of ‘relative’ emissions, notably the comparison between land-based and ship-based emissions, as well as issues relating to transport, deposition and environmental impacts, are considered in Appendix 2.

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\(^1\) See section 1.1 for definition of European marine areas.
\(^2\) These studies are reviewed more comprehensively in Appendix 2.
A1: 1 Levels and Characteristics of Shipping Traffic in European Waters

Most estimates of ship emissions, including SO₂ and NOₓ, adopt what may be termed a “bottom-up approach.” Such estimates generally begin with an assessment of various shipping characteristics, many of which thus constitute important parameters in characterising the sector for policy analysis purposes. These characteristics are subsequently combined to generate estimates of emissions. The following parameters are among those typically addressed for the study area(s) and time period concerned:

- numbers of ship movements;
- numbers of port visits;
- average voyage duration;
- traffic patterns and distribution;
- numbers of individual vessels constituting the ‘fleet’;
- fleet composition (vessel types, tonnage, engine types, etc.);
- fuel characteristics and consumption rates; and
- quantities and geographic patterns of emissions.

This and subsequent sections review the significance of each of the above characteristics and summarise the current state of knowledge concerning them either globally and/or, where available, specifically for ships plying ‘European’ marine areas. It begins by providing geographic definitions of the four marine areas being considered by the present study.

A1: 1.1 Definition of European marine areas

The geographic areas under consideration throughout the present study are shown in Figure 2.1 (Chapter 2). Basic information on each of the areas is provided in Table 1.1 below.

It should be noted that the area of the Northeast Atlantic (Area #4 above) considered herein—c. 1.5 million km²—is much smaller than that used by EMEP, and associated emissions studies, to assess the contribution of ships to atmospheric deposition in Europe. These latter considered a total area of well over 23 million km². By considering a smaller area of the Northeast Atlantic, the present study is able to focus more directly on areas where EU policy making may potentially be effective, since much of the marine area considered by EMEP et al clearly lies beyond the EU’s regulatory reach.

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3 This study defines ‘European waters’ to include the areas delineated in Table 1.1. In contrast, the term ‘EU waters’ is used to refer to EU territorial and jurisdictional waters, i.e., to the edge of the 200-mile EEZ, where this exists.
A1: 1.2 Assessing vessel movements, port visits and shipping concentrations

A1: 1.2.1 Numbers of vessel movements / voyages

While it may seem at first glance a straightforward exercise to quantify vessel movements taking place within a defined marine area over a given period of time, or the number of visits to ports within that area, this is generally not the case. One problem in the EU context is the lack of comprehensive or comparable national data from EU member states concerning the transport of goods and passengers by sea or visits by ships to European ports. Nevertheless, the issue is of great importance to the present study, both as a source for various emissions estimates as well as in its relevance for gauging the costs and impacts of various EU policy options.

<table>
<thead>
<tr>
<th>Marine study area</th>
<th>Description</th>
<th>Estimated area (km²)</th>
<th>Source of area estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Baltic</td>
<td>The Baltic Sea proper along with the Gulf of Bothnia, the Gulf of Finland and the entrance to the Baltic Sea bounded by the parallel of the Skaw in the Skagerrak at 57° 44.8’ N</td>
<td>422,000</td>
<td>Times Atlas of the Oceans, 1992</td>
</tr>
</tbody>
</table>
| 2 – Northwest European waters | Includes the North Sea and its approaches, the Irish Sea and its approaches, the Celtic Sea, the English Channel and its approaches and part of the North East Atlantic immediately to the west of Ireland. The area is bounded by lines joining the following points:  
- 48° 27’N on the French coast  
- 48° 27’N; 6° 25’W  
- 49° 52’N; 7° 44’W  
- 50° 30’N; 12°W  
- 56° 30’N; 12°W  
- 62°N; 3°W  
- 62°N on the Norwegian coast  
- 57° 44.8’N on the Danish and Swedish coasts  
This is the area defined in Annex I of MARPOL. | 1,572,597 | Calculated |
| 3 – Mediterranean | The Mediterranean Sea area means the Mediterranean Sea proper including the gulfs and seas therein with the boundary between the Mediterranean and the Black Sea constituted by the 41° N parallel and bounded to the west by the Straits of Gibraltar at the meridian of 5°36’ W. | 2,505,000 | Times Atlas of the Oceans, 1992 |
| 4 – Northeast Atlantic | | 1,511,801 | Calculated |

Total 6,011,397

This shortcoming is being addressed through Council Directive 95/64/EC of 8 December 1995 on statistical returns in respect of carriage of goods and passengers by sea. Under this Directive, harmonised statistics will need to be kept on all ports handling more than one million tonnes of goods or having more than 200,000 passenger movements annually. In most cases, full implementation of the Directive will begin on 1 January 2000.
An early and significant\(^5\) emissions inventory prepared by Marintek roughly estimated vessel movements and patterns, and resulting emissions in an area that included the North Sea, English Channel and the Baltic Sea. The study estimated broad ship movement patterns based on information presented in the United Nations’ *International Seaborne Trade Statistics Yearbook* (1984-85). However, trade figures are a fairly coarse method of estimating shipping patterns, a fact which may have had something to do with the apparently significant degree of underestimation of emissions by the study.

The main source generally used by subsequent emissions studies for quantifying ship movements within defined marine areas has been Lloyd’s Maritime Information Service (LMIS), which maintains proprietary information on individual vessel movements,\(^6\) generally including all vessels over 250 gross registered tons (GRT).\(^7\) LMIS data has been used in several important studies, including CONCAWE (1994), Lloyd’s (1995) and Lowles and ApSimon (1996).

CONCAWE (1994) seems to have been the first emissions study to rely on actual ships’ movement data from Lloyd’s, along with data from ferry operators. Here, the study area consisted of the English Channel and Southern North Sea, an area of some 70,000 km\(^2\). Within this area, approximately 204,000 ‘non-ferry’ vessel movements and 80,900 ferry movements were estimated to have taken place in 1992. These figures excluded ships below 250 GRT, as well as fishing and naval vessels and pleasure craft.

An important study by Lloyd’s (1995) looked at the north-eastern Atlantic Ocean, including the North Sea, the Norwegian Seas, the Irish Sea and the English Channel. The Lloyd’s study area of approximately 23.2 million km\(^2\) was equivalent to the above-mentioned ‘EMEP area,’ except that it excluded the Baltic and Mediterranean Seas. Within this area, during 1990, Lloyd’s estimated a total of 625,000 shipping movements. This figure appears to have been derived by extrapolating from the 37,145 vessel movements provided by LMIS and 10,919 ferry movements listed in operators’ schedules or international timetables, during two two-week study periods.\(^8\) Naval vessel, small craft and fishing vessel movements were generally excluded. The study conducted an inter-comparison of these figures with port authority records of the 13 busiest ports within the study area; the two sets of figures were generally within 10% of one another for individual ports.

Finally, Lowles and ApSimon (1996), which looked at the English Channel and Southern North Sea,\(^9\) reported more than 290,000 ship movements annually within its study area. It is not clear, however, whether this is an independent count or one that relies on CONCAWE (1994).

Table 1.2 summarises the findings of previous studies concerning ship movements.

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5 The Marintek emissions inventory (Bremnes 1990) is significant as, for a number of years, it formed the basis for EMEP’s estimates of the contribution made by shipping to European transboundary acidification. This was despite its incompleteness, i.e., the fact that it only estimated emissions from international trade, and excluded passenger ships, service vessels and non-carrying vessels, as well as ships hotelling or at anchor (ApSimon 1998).

6 For purposes of the present study, the term ‘vessel movements’ will be used to refer to trips made between ports only, and will exclude intra-port movements or dockings.

7 CONCawe (1994) has estimated the degree of coverage obtained through this method at 97% of emissions.

8 \((37,145 + 10,919) \times 52/4 = 624,832\) shipping movements annually.

9 Boundaries used were, in the north, from Great Yarmouth to Den Helder and, in the south, from Portland Bill to Cap de la Hague.
within variously defined European marine areas.

### Table 1.2: Summary Comparison of Vessel Traffic Estimates Used by Emissions Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Study area</th>
<th>Year of estimate</th>
<th>Estimated ship movements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bremnes (1990) (Marintek)</td>
<td>North Sea, English Channel and Baltic</td>
<td>N.A.</td>
<td>N.A.</td>
</tr>
<tr>
<td>CONCAWE (1994)</td>
<td>English Channel, Southern North Sea</td>
<td>1992</td>
<td>204,000 ‘non-ferry’ 89,000 ferry</td>
</tr>
<tr>
<td>Lloyd’s (1995)</td>
<td>North-eastern Atlantic – North, Norwegian &amp; Irish Seas, English Channel</td>
<td>1990</td>
<td>483,000 ‘non-ferry’ 142,000 ferry</td>
</tr>
</tbody>
</table>

#### A1: 1.2.2 Port Visitation

As noted above, EU-level statistics on port visitation do not yet exist. National-level statistics are also often of a patchwork nature. However, a variety of sources do exist regarding individual ports and their visitation patterns, which can be pieced together to form a relatively coherent whole. These sources include Lloyd’s *Ports of the World*, the *Fairplay Ports Guide*, and information available from individual ports, many of which now maintain World Wide Web sites. This information has been brought together for the purpose of the present study to provide a quantitative overview of port visitation at EU member state ports.

Based on a careful review of the above sources, Table 1.3 provides estimated port visitation and cargo handling totals by EU member state.

### Table 1.3: Estimated Port Visits and Cargoes Handled Annually

<table>
<thead>
<tr>
<th>Country</th>
<th>Marine area(s)*</th>
<th>Est. total port visits</th>
<th>Est. total cargoes ('000 t)</th>
<th>Average cargo per vessel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>2</td>
<td>35,398</td>
<td>193,181</td>
<td>5,457</td>
</tr>
<tr>
<td>Denmark</td>
<td>1,2</td>
<td>121,037</td>
<td>126,151</td>
<td>1,042</td>
</tr>
<tr>
<td>Finland</td>
<td>1</td>
<td>29,261</td>
<td>85,142</td>
<td>2,910</td>
</tr>
<tr>
<td>France</td>
<td>2,3,4</td>
<td>41,464</td>
<td>307,080</td>
<td>7,406</td>
</tr>
<tr>
<td>Germany</td>
<td>2</td>
<td>155,488</td>
<td>349,920</td>
<td>2,250</td>
</tr>
<tr>
<td>Greece</td>
<td>3</td>
<td>43,539</td>
<td>40,074</td>
<td>920</td>
</tr>
<tr>
<td>Ireland</td>
<td>2</td>
<td>17,746</td>
<td>38,936</td>
<td>2,194</td>
</tr>
<tr>
<td>Italy</td>
<td>3</td>
<td>47,718</td>
<td>299,168</td>
<td>6,270</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2</td>
<td>46,635</td>
<td>384,496</td>
<td>8,245</td>
</tr>
<tr>
<td>Portugal</td>
<td>4</td>
<td>12,123</td>
<td>48,495</td>
<td>4,000</td>
</tr>
<tr>
<td>Spain</td>
<td>3,4</td>
<td>75,081</td>
<td>268,846</td>
<td>3,581</td>
</tr>
<tr>
<td>Sweden</td>
<td>1,2</td>
<td>64,118</td>
<td>145,575</td>
<td>2,270</td>
</tr>
<tr>
<td>UK</td>
<td>2</td>
<td>246,840</td>
<td>596,521</td>
<td>2,417</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>936,447</td>
<td>2,883,584</td>
<td>3,079</td>
</tr>
</tbody>
</table>

* See Table 1.1 for definition of marine areas. Sources: Lloyds (1997); Fairway (1999)
Figures 1.1 and 1.2 present the results of the port visitation survey of ship visits and cargoes, broken down by marine area. They demonstrate that the majority of both port visits and cargoes handled are within the North West European area.

In addition to commercial ship visitation, the survey also looked at ferry traffic visitation to EU ports. It concluded that at least 144,000 ferry visits took place to EU member state ports, delivering upwards of 130 million passengers.
A1: 1.2.3 Comparing vessel movement and port visitation data

There are subtle but important distinctions to be made between vessel movements and port visitation figures, and these differences are of direct significance to the present study. The distinctions can be summarised by considering whether a particular vessel movement / voyage takes place:

1. within the study area,
2. into the study area,
3. out of the study area, or (4) through the study area (CONCAWE, 1994).

While voyage ‘types’ 1 and 2 result in a port visit within the study area, voyage types 3 and 4 do not.

Table 1.4 illustrates this distinction, using CONCAWE data on voyage types for the English Channel and southern North Sea. According to these figures, some 60% of non-ferry movements involved vessels heading either into or out of the study area, 28% were entirely within the area and 12% represented through traffic. In the case of ferry movements, some 95% of such movements were between study area ports, i.e., within the study area. As a percentage of total ferry and non-ferry movements, through traffic accounted for only 8% of vessel movements.

<table>
<thead>
<tr>
<th>Voyage type</th>
<th>Vessel movements</th>
<th>Port visits</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vessel movements</td>
<td>Port visits</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Non ferries</td>
<td>Ferries</td>
<td>Non ferries</td>
<td>Ferries</td>
</tr>
<tr>
<td>1 – Within area</td>
<td>58,000</td>
<td>85,000</td>
<td>58,000</td>
<td>85,000</td>
</tr>
<tr>
<td>2 – Into area</td>
<td>61,000</td>
<td>2,000</td>
<td>61,000</td>
<td>2,000</td>
</tr>
<tr>
<td>3 – Out of area</td>
<td>61,000</td>
<td>2,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4 – Through traffic</td>
<td>24,000</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>204,000</td>
<td>89,000</td>
<td>119,000</td>
<td>87,000</td>
</tr>
</tbody>
</table>

Source: Vessel movements from CONCAWE (1994)

A1: 1.2.4 Voyage distance and duration

In addition to the sheer number of ship movements, it is generally necessary in preparing emissions estimates to gain an idea of voyage distance and duration. Depending partly on the size of the marine area being studied, voyages may last anywhere from a few hours or less—as is true for many ferries—to several days or more, with obvious implications for total energy use and emissions. By combining information on vessel movements with voyage duration data and estimates of vessel speed, estimates can be made of total vessel days and total vessel nautical miles travelled within a given time period and marine area.

10 Confusingly, the CONCAWE study refers in its summary and elsewhere to 290,000 + ship movements and 270,000 port visits. However, while the number of ship movements is restricted to vessels exceeding 250 GRT, no such qualification is placed on the port visits data, i.e., ships smaller than 250 GRT are obviously being counted.
While port visitation data cannot provide information on average voyage lengths, the above-described Lloyd’s sources generally indicate both voyage duration as well as the ports of origin and destination for each trip, which can be used to estimate voyage distance and average speed. A concern here in estimating energy conversion and emissions is when to begin counting, i.e., transit time beyond the boundary of the study area—which may be a substantial portion in the case of longer-distance voyages—must be excluded from the summation.

As far as the emissions studies cited in the previous section are concerned, the Concawe (1994) and Lloyd’s (1995) studies both estimated the duration of individual voyages within their respective surveys. In the case of the Lloyd’s study, this was done by mapping the known route and then calculating the distance covered across the entire route and across individual grid squares along the route. It is unclear from this or the Concawe study, however, what were the actual average voyage lengths, either within or outside of their respective study areas.

Another source of information on typical voyage duration is the EMARC project. Table 1.5 shows EMARC’s conclusions regarding average voyage duration, based on a survey of nearly 1,500 ships operating in EU waters. Unfortunately, these figures are based on a survey which asked respondents to indicate voyage duration within a fairly wide range, somewhat limiting the usefulness of the results. In addition, it is likely that the voyages include substantial portions of time spent beyond the boundaries of the study area.

### Table 1.5: Average Voyage Duration, by Ship Type (in Percent)

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Average voyage duration in Hours</th>
<th>Days</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;5</td>
<td>5-12</td>
</tr>
<tr>
<td>Tanker</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>OBO/Bulk</td>
<td>0</td>
<td>1.7</td>
</tr>
<tr>
<td>Cruise</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Ferry</td>
<td>46.6</td>
<td>26.1</td>
</tr>
<tr>
<td>Container</td>
<td>0</td>
<td>2.3</td>
</tr>
<tr>
<td>Animal carrier</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Dry cargo</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Reefer</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Deep sea tug</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fishing vessel</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Other</td>
<td>11.3</td>
<td>0.8</td>
</tr>
<tr>
<td>All vessels</td>
<td>10.8</td>
<td>6.0</td>
</tr>
</tbody>
</table>

Source: EMARC 1996.

### A1: 1.2.5 Traffic patterns and concentrations

The main traffic pattern within NW European waters is to and from the major ports of the Netherlands, Belgium, Southern England, Northern France and Northern Germany, which inevitably uses the English Channel. The traffic flows through Traffic Separation Schemes (TSS) in the Dover Strait and the Southern North Sea and has been subject to radar surveillance for many years. As a result, it is well identified, quantified and understood.
In terms of overall traffic density, there is effectively a “highway” of activity through the English Channel, which diverges North of Dover, with vessels diverting into the Schelde, Rotterdam and the East coast of the UK, and other traffic continuing North, principally to the Weser (Bremen and Bremerhaven), the Elbe, for Hamburg, and to the Kiel Canal for the Baltic. At the Western end of the Channel (Ushant) the “highway” splits, with vessels either heading South or West for North America. It is also worth noting that traffic heading north up the Channel will tend to be on the French side, and south-bound traffic on the English side; this has potential implications for emissions in that deep-sea vessels heading south will tend to have bunkered in Rotterdam or another northern European port, whereas north-bound traffic will be using bunkers obtained elsewhere.

Quantifying the above traffic patterns in order to determine the specific location of emissions is a complex task. It is possible using LMIS data on the ports of origin and destination of individual ships to create geo-referenced data (maps) concerning voyage and thus emissions patterns from individual ships. This type of information is particularly useful once the stage is reached whereby emissions patterns are to be transformed into patterns of deposition. Lloyd’s (1995) used this method to create maps showing the distribution of various pollutants, including SO$_2$, NO$_x$, CO and HC, and thus of ships, in European waters.

A quite different method of determining traffic patterns is presented in section 3 below.

A1: 1.3 Ship and engine numbers, types and characteristics

A1: 1.3.1 Numbers of vessels

Section 1.2 above presented estimates of the annual number of port visits taking place in European waters. However, it did not address the question of how many individual ships were involved in these visits. This information is particularly important for estimating ship-specific investment costs, e.g., for NOx control, as opposed to estimates related to fuel consumption, which do not directly depend on the number of ships involved.

The world fleet of ships greater than 250 GRT was reported as 58,000 in 1992 (CONCAWE 1994). These vessels had a combined tonnage of 442 million GRT, or a mean figure of 7,620 GRT per vessel. Together, they were estimated to account for some 97% of total emissions from ships, the remaining 3% being generated by ships smaller than 250 GRT.

How many of these ships conduct at least part of their operations in European waters during the course of a given year? Unfortunately, there is no clear answer to this question. However, by reviewing existing information, we may arrive at some reasonable estimates.

CONCAWE’s survey of ships operating in the English Channel and southern North Sea in 1992 identified a total of 12,200 different vessels above 250 GRT, 80 of which were ferries (CONCAWE 1994). The 11,400 non-ferries were responsible for 204,000 ship movements and 119,000 port visits during 1992, or an average of 17.9 movements and 10.4 port visits per ship.

The Lloyd’s survey (Lloyd’s 1995) was conducted over a wider geographic area but a shorter period of time—two two-week periods. During the first two-week period, the survey identified 6,899 vessels undertaking 18,512 movements. During the second
period, 6,785 vessels made 18,633 movements. During the two periods combined, a total of 9,538 vessels were responsible for 37,145 vessel movements, or an average of 3.9 movements per ship. It is worth noting that a total of 4,146 ships moved through the area during both of the two periods.\textsuperscript{11}

One way to extrapolate from these figures is as follows. Beginning with an area—such as the English Channel and Southern North Sea—where the number of active ships and port are known, it is possible to envisage an expansion of this area to encompass a larger one, such as the entire North Sea. In doing so, one may assume as an outer limit that the ratio of numbers of different ships:port visits would be equal to that of the original area. Thus, for example, given that the English Channel and Southern North Sea had 119,000 port visits by 11,400 commercial vessels over 250 GRT in 1992, or 10.4 visits per ship, then the entire North Sea’s 533,000 port visits should have been conducted by no more than 51,060 such vessels.

There are two reasons to conclude that the actual figure is substantially lower. First, the entire world fleet consists of only 58,000 vessels over 250 GRT; clearly, 88% of the world’s commercial vessels do not operate in the North Sea during a given year.\textsuperscript{12} Second, logic suggests that as the borders of the area under consideration expand, the number of different ships in operation will expand at a steadily decreasing rate, as already-counted ships visit ports within the newly expanded area. In fact, this principle is clear from the two data points which we have, those for the southern North Sea and English Channel (11,200 for 119,000 port visits) and that for the world (58,000 for some 3-4 million port visits worldwide). \textbf{Figure 1.3} illustrates this principle and provides a rough indication of the numbers of ships over 250 GRT likely to be operating within European waters in any given year. Thus, for the purpose of considering the potential impacts of various regulatory and other options, this study will use a figure of 30,000 ships, or just over half of the world’s fleet.\textsuperscript{13}

\textbf{A1: 1.3.2 Ship types}

While it is possible to prepare a bottom-up emissions inventory based on total annual vessel days and/or nautical miles combined with emission factors, the reliability of such estimates is enhanced if vessel days can be disaggregated by vessel type. Different ships generate waste and emissions at vastly different rates. Thus, it may not be enough to know that 100,000 ships pass through a particular marine area annually without some idea of the relative proportions of, e.g., cruise liners, oil

\textsuperscript{11} This is clear from the fact that a total of 13,684 ships are reported from the two periods separately, but only 9,538 from the combined periods.

\textsuperscript{12} Adding in the Baltic at the same rate would require 123% of the world’s fleet to have been active in the combined area!

\textsuperscript{13} It should be noted that expanding the time period beyond one year would have a similar effect as expanding the area. Thus, over a multi-year period, the total number of ships operating in European waters would increase, albeit at a decreasing annual rate.
tankers and fishing vessels—each of which has its own typical emission factors.\textsuperscript{14}

In the case of \( \text{SO}_2 \) emissions, the importance of ship type is mainly related to fuel consumption. Thus, assuming a constant level of sulphur in fuel, e.g. 2.5\%, a given ship’s emissions will depend on its rate of fuel consumption, which in turn depends on ship and engine size, type and ship speed. For other pollutants such as \( \text{NO}_x \), emissions also depend on ship-specific characteristics relating to the combustion conditions, such as temperature and pressure, and are thus more difficult to estimate and may be less accurate.

Studies in this area, e.g., EMARC (1996) have used ten or more categories of vessels—e.g., tankers, cruise ships, ferries, container ships, etc.—each of which are assigned relevant fuel consumption levels, emission factors, etc.

Most of the emission inventories carried out to date have used shipping position information or statistics gathered in the period 1990-92. The general overall pattern of trade has altered somewhat since then. The carriage of both liquid and dry bulk cargo has increased steadily in line with general economic growth, but there has been a continued swing towards containerisation of general cargo, to the point where container traffic has, in broad terms, doubled since that date. From an air emissions perspective, this picture is confused by the trend towards increased size in deep-sea liner container vessels, trading into a number of major container ports, with onward transport by smaller feeder container vessels.

\textit{A1: 1.3.3 Engine types}

Virtually all commercial vessels are now propelled by diesel engines. Engine types reported by Corbett and Fishbeck (1995), based on Lloyds Maritime Information Service, are shown in Table 1.6.

Steam vessels have significantly higher fuel consumption than motor vessels, and consequently the proportion of steam vessels is small and is declining. Steam vessels tend to use the lowest grade of residual fuel, generally referred to as Bunker C, with a nominal viscosity of 500 centistokes. However, the remaining steam vessels tend to be large tankers, where steam propulsion has remained popular as it also provides a power source for running cargo pumps while in port. Thus steam propelled vessels burning low grade fuel still represent a significant user of low-grade fuel and potentially create a high level of in-port pollution. There are still a significant number (17\%) of steam-driven naval ships, but this is attributable to the higher average age of naval vessels, and the perceived need for a low acoustic signature.

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
\textbf{MACHINERY TYPE} & \textbf{NO OF SHIPS} & \% \\
\hline
Slow speed diesel & 56,628 & 65.7\% \\
Medium speed diesel & 27,758 & 32.2\% \\
Steam & 1,820 & 2.1\% \\
Total & 86,206 & 100\% \\
\hline
\end{tabular}
\caption{Engine Profile (by percentage)}
\end{table}

Note: Refers to ships over 100 GRT
Source: Corbett & Fishbeck (1999)

\textsuperscript{14} Estimates, which ignore ship type, may be based on information concerning the global fleet along with the assumption of a representative sample thereof within the area being studied. Such a simplifying assumption may become increasingly untenable in the case of smaller and less frequently travelled marine areas.
Lloyd’s (1995) also considered the characteristics of nearly 10,000 ships within its survey. Relevant characteristics included ship type, gross tonnage, numbers and types of main engines, main engine power, generator power and service speed. Figures 1.4 & 1.5 below provide a breakdown of ships surveyed according to propulsion type, service speed and total power.

It may be noted that the main engine type distribution used in the Lloyds Register study (1995) shows a somewhat different distribution by engine type, with nearly equal proportions attributed to slow-speed and medium-speed diesels. This is because the Lloyds Study was based on two samples of vessels in the NW Europe area during specified time periods rather than being based on overall fleet statistics, which suggests that there may be a higher proportion of medium-speed engined vessels operating in European waters.

### A1: 2 Marine bunker fuels

In the absence of exhaust scrubbing systems, the quantity and average sulphur level of bunker fuels consumed within a particular marine area fully determines the levels of S emissions from ships within that area. Fuel consumption is also a key factor in determining NOx emissions. Not surprisingly, bunker fuel consumption and sales represent key potential targets for EU policies. This section therefore addresses the issue of marine fuel, or bunker sales and consumption, both globally and, more particularly, in European waters.

#### A1: 2.1 Fuel types

Marine bunkers are generally categorised as either “distillates” or “residual fuels.” There are two types of marine distillates:

- Marine gas oil, which is purely a distillate (MGO);
- Marine diesel oil (MDO), which is a heavier distillate fuel sometimes containing a portion of residual fuel oil.

Typically, the above marine distillates are used for the main engines of small vessels and auxiliary engines of larger vessels. Diesel is also used at times when manoeuvring in port and in parts of Scandinavia (Appendix 3, section 1.2).
Larger vessels typically utilise heavier marine fuels, which are classified according to viscosity. Marine uses account for some 20% of total fuel oil demand. (Swinden, 1995). Bunkers range through intermediate fuel oils (IFO) to the heaviest residual (typically bunker C). The heavy fuel oils are mainly the residues created during the refining process.

Marine fuels conform to the specifications of ISO 8217.

**A1: 2.2 Sales/consumption levels and trends**

Globally, marine bunker fuel sales / consumption rose from 95.8 million metric tonnes in 1965 to 146.8 million tonnes in 1988, for an annual compound growth rate of 1.8%. The peak year for sales during this period was 1980, with a total of 152.2 million tonnes consumed globally (Cockett, 1990). From 1988 to 1996, the annual growth rate for consumption was 1.6%, or slightly less than during the 1965-1988 period. From a low of 127.2 million tonnes in 1990, global marine bunker fuel consumption had risen to 166 million tonnes by 1996 (see Figure 1.6).

During the period 1990-96, EU member states supplied an average of 35.3 million tonnes of bunkers annually, or about 23.3% of the world total. Annual sales remained fairly consistent throughout the period, ranging from a low of 34.3 million tonnes in 1994 to a high of 37.1 in 1996. As shown in Figure 1.7, the Netherlands has been the leading supplier among EU member states, with an average of 11.4 million tonnes of sales annually between 1990-96, representing 32.2% and 7.5% of the EU and world totals, respectively. Seven other EU countries – Belgium, Spain, Greece, France, Italy, United Kingdom and Germany – each supplied over two million tonnes of bunker fuel annually during this period.

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15 Unless otherwise stated, calculations are based on data in the World Energy Database. Figures cover quantities of fuel delivered to sea-going ships of all flags, including warships and fishing vessels. However, sales to ships engaged in transport within inland and coastal waters is not included. Personal communication, Michael Maloney, US National Energy Information Center, 17 August 1999. Globally, it is assumed that annual sales = consumption. This is not assumed to be the case for EU member states sales and European marine areas consumption (see below).
Box 1 presents a brief case study of the Danish market for marine bunkers. This is not presented as a typical case, rather it is an example of some of the factors that contribute to bunker supply, demand, quality and price.

Box 1: Denmark’s market for marine bunkers

Denmark supplies about 1.5 million tonnes of marine bunkers annually. Some 80% of this total consists of ‘offshore bunkering,’ the main locations of which are in the Great Belt region and offshore Copenhagen / Oresund. They represent so-called ‘bunker-only stops.’ It is worth noting in this context that the decision to bunker offshore versus in port often depends on careful calculations involving bunker costs and the cost of time. Ships that bunker in port, while loading or unloading, avoid the delays of a ‘bunkers-only’ offshore stop. However, this difference tends to be reflected in cheaper prices for offshore bunkers.

The majority of bunker buyers in the Danish market are international vessels passing in and out of the Baltic Sea, destined e.g., for St. Petersburg, the Baltic States, Finland and Sweden. These include a large proportion of dry cargo vessels and reefers.

Denmark is at a competitive disadvantage due to the fact that it has to import fuel for the marine market. The added transport costs involved mean that competitors, notably the Baltic States, as well as some Polish ports and St. Petersburg in Russia, have a cost advantage. In fact, IFOs and distillates are mostly imported from the Baltic States, Poland and Russia.

In addition, Danish refineries only refine low sulphur crude oils. For example, Shell has a refinery in Fredericia, which receives low sulphur North Sea oil by pipeline. This puts them in a good competitive position to supply low sulphur products. It is believed by some that the price differential between IFOs and distillates in Northern Europe will narrow as demand for HSFOs declines due to environmental and other factors. Then the low sulphur distillates sector would become of substantially greater interest, leaving Denmark in an ideal position. In the meantime, the majority of demand is still for HSFOs.

Source: Bunkerworld.

A1: 2.2.1 Sales by fuel type

In addition to looking at overall bunker fuel sales, it is important to distinguish
between sales of residual fuels and distillates, since average sulphur levels differ significantly for each category (see A1:2.6.1, below). As shown in Figure 1.8, from 1990-96, an average of 111 million tonnes annually, or 74% of marine fuels consumed globally were residual fuels, while the remaining 40 million tonnes, or 26% were distillates, such as marine diesel oil (MDO).

![Figure 1.8: EU and world residual fuel consumption, as % of total bunker sales, 1990-96](image)

Of the average 35.3 million tonnes of bunkers supplied by EU countries annually from 1990-96, 27.0 million tonnes, or 76%, consisted of residual fuels, while an additional 8.3 million tonnes was distillate fuel oil and other products. Given an average of approximately 750 tonnes per ‘bunkering’ (Cullen 1997), these figures suggest some 47,000 European ‘bunkerings’ annually.

Time-series data show a long-term trend towards a reduced percentage of residuals in total fuel sales/consumption. In 1969, the proportion of residuals : distillate fuels was as high as 88:12. By 1996 (see Figure 1.8), the figure had dropped to 70:30.

It is also worth noting that, from 1990-96, world residual fuel consumption tended to represent a lower and more rapidly decreasing percentage of total fuel consumption than was the case for EU countries (see Figure 1.8). Given that residual fuels have a substantially higher average sulphur content than distillates, this has some significance for emissions levels. A more rapidly decreasing proportion of residual fuel sales by EU countries would tend to have a positive impact on S emission levels over European waters.

Table 1.7 shows the relative percentage of non-residual fuels within the total fuels supplied by various EU member states in the 1990-96 period. Inevitably this picture will change with time, especially with the introduction of national policies such as the Swedish incentive scheme (Appendix 3).

### A1: 2.3 Production

16 Individual bunkering, however, can vary from as little as 80 to as much as 16,000 tonnes.
17 Corbett (1999) uses figures of 2.7% and 0.5% average S content for residuals and distillate fuels, respectively.
18 It should be noted, however, that lowering average S levels does not only depend on a switch from residuals to distillates, since each type of fuel can have different S levels. Thus, switching from a high-sulphur to a low-sulphur residual fuel (e.g., based on a sweeter crude) can in some cases have a greater impact than changing from a residual to a distillate fuel.
A survey conducted by CONCAWE in 1989 provides a picture of the production and supply of bunkers by European refineries (CONCAWE 1993). The survey, which ultimately covered 83 of the 117 refineries operating in OECD-Europe, identified the following distribution of marine bunker production:

- 31 refineries, mainly those operating inland, had no involvement in the bunker business.
- 31 refineries produced quantities that were either less than 200,000 tonnes per year or less than 5% of their total production.
- 21 “primary BFO refineries” produced 15.6 million of the 17.7 million tonnes per year of bunker fuel reported in the survey.

The survey estimated that, overall, OECD-Europe’s production of bunker fuel oil (BFO) was 21 million tonnes in 1989. An additional 5 million tonnes was imported from outside Europe.

A1: 2.4 Prices

Marine bunker prices show substantial variation over time and location. More important perhaps, for the purpose of the present study, are typical differences exhibited between fuel types, including marine diesel oil (MDO), marine gas oil (MGO), ‘high-sulphur heavy fuel oil’ (HSHFO) and ‘low-sulphur heavy fuel oil’ (LSHFO).\(^{19}\)

Figures 1.9 and 1.10 present comparative bunker fuel prices from Northern European and Southern European ports, respectively. The following observations are made:

- There is a fair amount of variation in price, particularly between fuel types, but also for the same type between ports. There is also fairly frequent variation, due to changing supply and demand conditions.
- The price premium payable for marine diesel oil over intermediate fuel oil 180 ranged from $36 in Antwerp to $65 in Gibraltar and Genova. According to Nurmi (1998), the long-term worldwide price differential between HFO and MDO has tended to be in the range of $60

\(^{19}\)As previously noted, this study sets the dividing line between LSHFO and HSHFO at 1.5% S.
to $80 / tonne.

- In percentage terms, Antwerp showed a low 37% premium and Gibraltar a high premium of 61%.
- On average, the MDO premium for five Northern European ports was 44% and $45 per tonne, while for Southern European ports, the figures were 56% and $61.

As for the difference between LSHFO and HSHFO, Liddy (1998) indicates that the historical price premium has varied from $2 per tonne to $43 per tonne. During the course of this study a Swedish bunker supplier quoted a $10 - $20 premium and Shell (private communication) stated ‘The price gap between 3.5% S Fuel Oil and 1% S Fuel Oil has averaged around $15/t in the Mediterranean and $10/t in Rotterdam. The high demand for 1% Fuel Oil in the Italy is one cause of the higher differential. So a higher call on low sulphur fuel oil does cause the gap to widen.’

A fuller examination of these price variations and the derivation of a model for use in this study is given in Appendix 5, section 5.8.

**A1: 2.5 Fuel choice vs. overall fuel and maintenance costs**

One factor which needs to be considered in discussions of the costs of potential low S mandates is that the choice of fuel can have important impacts on overall operational costs. Such cost differences tend to operate in favour of higher quality—in this case lower S—fuels and as a result tend to lower the net cost of using low S fuels.

Some of the benefits associated with operating ship engines on low S fuels—including MDOs—are as follows:

- Reduction in the tendency towards cold corrosion (MER 1996). For example, an estimated 30-40% reduction in maintenance cost may be associated with burning MDO instead of HFO (Nurmi 1998).
- Increased potential for exhaust gas heat recovery due to reduced corrosive effects (MER 1996).
- A low-S fuel has a higher specific energy than a comparable high-S fuel, with the specific energy increasing at a rate of 0.8% for each 1% decrease in S content. As a result, substituting 1.5% S fuel for 3.5% will lead to a fuel consumption savings of 1.6% (CONCAWE 1993).
- Continuous use of low-S fuels allows a lubricant of lower alkalinity to be used, with a resulting savings of $1-1.50 / ton of fuel (CONCAWE 1993).

**A1: 2.6 Fuel sulphur levels**

**A1: 2.6.1 Maximum and average S levels**

Marine fuels are required to meet a series of specifications, depending on their category. These specifications are defined in ISO-8217 (1996), which includes specification requirements for four marine distillates and 15 ‘intermediate’ or residual fuel grades. These specifications define, *inter alia*, the maximum acceptable S-level for the bunker type in question (Cullen, 1997).

The four marine distillates, known as DMX, DMA, DMB and DMC, have maximum allowable S levels of 1.0%, 1.5%, 2.0% and 2.0% respectively. Of the 14 grades of marine residual fuels, three have a maximum S level of 3.5%, one a maximum of 4% and the remainder have maximum S levels of 5.0%.
Fuel testing is an important source of information on S levels. Fuel testing analysis services include Lloyd’s Register’s Fobas and Veritas Petroleum Services (VPS), which is a subsidiary of Det Norske Veritas. VPS estimates that 20-30 per cent of deliveries worldwide are subject to fuel testing. Testing services report substantial increases in business in recent years. DNV Petroleum Services (DNVPS) is responsible for about 70% of periodic testing currently performed, analysing more than 50,000 samples annually. It receives samples from more than 1,000 ports worldwide, delivered by more than 800 suppliers and representing over 8,000 ships (Cullen, 1997).

According to data collected by DNV, from 1990 to 1996, worldwide average sulphur levels remained fairly constant at between 2.75 and 2.95 mass % S. In 1996, average S content of bunker fuels worldwide was about 2.8% (Cullen 1997).

Figure 1.11 shows average S levels for the two most important viscosity grades of marine fuels, known as IFO 180 and IFO 380, both worldwide and for Rotterdam. Based on sampling records of DNV Petroleum Services (Cullen 1997), these grades may account for over 90% of IFO sales. As shown in the figure, the higher viscosity fuels, known collectively as IFO 380, tend to have slightly higher average S levels than do the lower viscosity, IFO 180 fuels.

It is also apparent from Figure 1.11 that bunkers supplied by Rotterdam tend to be significantly higher than the worldwide average. Similarly, averaging the annual average S levels for the Netherlands as a whole for the period 1990-96 gives an overall figure of 3.05%, compared with figures of 2.35% for the UK and 2.54% for the US.

Figure 1.12 points to the low level of samples exceeding 4% S from 1988-91. It may be indicative of the limited extent to which IMO’s Annex VI will have an impact on current levels of S emissions.
A1: 3 A Top-Down Approach to Estimating Ship Emissions

A1: 3.1 Bottom-up vs. top-down approaches

In estimating quantities of various waste streams being generated by ships within geographically defined areas, two broad methods are possible. The first method, which may be termed ‘bottom up’, requires detailed quantification of shipping patterns within the marine area(s) under study. Such methodologies have been used by past studies to estimate ship atmospheric emissions from some of the European marine areas presently under study, including the Northeast Atlantic, southern North Sea and English Channel and Baltic Sea (see Section 1 above and Appendix 2). However, taken as a whole, these studies failed to provide comprehensive and inter-comparable data for the four European marine areas under study.

Given the practical difficulties with using the above methodologies, simpler ‘top-down’ approaches have been attempted. These tend to rely on global estimates of factors such as fuel consumption and vessel type, combined with estimated emissions factors. For example, in estimating waste oil generation by ships operating in European waters, a recent study used a figure of 125 million tonnes of HFO consumption (1994), along with an estimated two per cent rate of sludge generation to estimate global oily waste generation for 1994 at 2.5 million tonnes (BMT and Plant, 1997).

Such top-down estimates, relying on fairly accurate global figures on fuel use, shipping types and emissions factors, are an excellent way of making global estimates of ship emissions, and may therefore make a useful contribute towards global inventories, such as those for various greenhouse gases. However, in order to make such estimates useful at regional and sub-regional levels, it is necessary to have a method of apportioning the global emissions pie. Thus, BMT and Plant (1997) used a figure of 1/3 of world ship cargoes being loaded or unloaded annually to suggest that a similar proportion (some 825,000 tonnes) of fuel refuse was being generated by ‘EU-related shipping.’ However, this was considered to be a fairly coarse estimate.


Corbett et al(1999) employs a top-down methodology to estimate global totals for various types of ship atmospheric emissions. Using 1993 global consumption figures of 109 million tonnes of residual bunkers and 38 tonnes of other bunkers, along with average sulphur levels of 3.3% and 2%, respectively, the study estimates global S emissions from ships at 4.24 teragrams (4.24 x 10^{12} i.e. 4.24 million tonnes). The study employs a similar method, also relying on global statistics regarding ship engine types, to create global NOx emissions estimates.

Corbett et al go on to suggest a simple yet ingenious method of geographically breaking down the above global ship emissions estimates. The method involves the use of data from the Comprehensive Ocean-Atmosphere Data Set (COADS), which consists of surface marine data for the world ocean covering more than 150 years. COADS Standard 1a data consists of a large database of location and weather observations made by merchant and naval mariners during the period 1980-1993. By plotting these observations, a sample approximating actual traffic distributions can be created. Corbett et al (1999) use the method to create a global emissions map, based on 1993 fuel use and COADS observation patterns, and suggest that the method may be of use to quantify emissions from individual marine areas.
A1: 3.3 Top-down estimates of SOx and NOx emissions from marine areas

Given the above-mentioned limitations and lack of flexibility in existing data, it was decided for the purposes of the present study to utilise and build upon the method suggested by Corbett et al (1999). An expanded data set was therefore obtained from COADS, showing the number of monthly observations made by ships in European waters, according to 1x1 latitudinal and longitudinal grid cells, during the period 1992-96. More than 58,000 summary data points, representing nearly 1.5 million ship observations, were summed by grid cell. By using a five-year period, much of the variability in the monthly and annual figures was smoothed out, and annual averages created.

Two assumptions were required in order to move from a regional distribution of COADS shipping observations to estimates of the regional distribution of fuel consumption and emissions. First, and most crucially, it was assumed that the location of ship observations represents an accurate proxy for the location of ships. While this seems in general a fairly reasonable assumption, at least two caveats apply. First, since COADS observations are generally made at six-hour intervals, it is unlikely that vessels on short and busy voyages, particularly ferries, would make them. Second, ships in port will also not make COADS observations. Thus, in general, marine areas having an above average concentration of ferry transit and port activities, e.g. the English Channel, should tend to have their emissions underestimated by this method, while emissions from open ocean areas will be overestimated.

A second assumption relates to whether or not ships in EU waters represent a fair ‘sample’ of shipping globally. This relates back to the discussion in section 1.3.2, which emphasised the importance of understanding the distribution of shipping types within marine areas under study. In the case of the European marine areas being considered by the present study, there is no apparent reason not to assume that their shipping represents an accurate sample of ship types.

Also required, of course, are global estimates of fuel consumption, NOx emissions and SOx emissions. These have been modified from Corbett et al (1999) global estimates for 1993 to reflect average global bunker fuel consumption figures from 1992-96.

In this way it has been possible to generate 1x1 degree maps showing the estimated annual distribution of SOX and NOX emissions (see Figures 1.13 and 1.14). The rather odd shape of the landmasses is due to the fact that where a grid cell includes both land and sea, this is generally recorded as sea, as it contains ship observation data. Thus relatively narrow landmasses, e.g. the UK, tend to disappear.

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20 Clearly, the tenability of the above assumptions, and the accuracy of the method in general, decreases along with the size of the marine area, and particularly at the level of individual grid cells. However, at the scale of major European marine areas, the method appears reasonable.
Fig. 1.13 Estimated Annual SOx Emissions by Ships, 1992-96 (t)
Fig. 1.14 Estimated Annual NOx Emission by Ships, 1992-96 (t)

EU Ship Emissions to Air Study
Table 1.8: Annual averages, based on COADS observations and global estimates, 1992-96

<table>
<thead>
<tr>
<th>MARINE AREA</th>
<th>ACTUAL SHIP OBSERVATIONS</th>
<th>% OF ESTIMATED WORLD TOTAL</th>
<th>S EMISSIONS (kt)</th>
<th>FUEL CONSUMED (kt)</th>
<th>SO2 EMISSIONS (kt)</th>
<th>NOx EMISSIONS (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NW Europe (Area 2)</td>
<td>626,590</td>
<td>8.0%</td>
<td>371</td>
<td>12,553</td>
<td>742</td>
<td>878</td>
</tr>
<tr>
<td>Mediterranean (Area 3)</td>
<td>330,193</td>
<td>4.2%</td>
<td>195</td>
<td>6,815</td>
<td>391</td>
<td>463</td>
</tr>
<tr>
<td>NE Atlantic (Area 4)</td>
<td>270,381</td>
<td>3.5%</td>
<td>160</td>
<td>5,417</td>
<td>320</td>
<td>379</td>
</tr>
<tr>
<td>Baltic (Area 1)</td>
<td>230,674</td>
<td>3.0%</td>
<td>137</td>
<td>4,621</td>
<td>273</td>
<td>323</td>
</tr>
<tr>
<td>All European waters</td>
<td>1,457,838</td>
<td>18.7%</td>
<td>863</td>
<td>29,207</td>
<td>1,726</td>
<td>2,044</td>
</tr>
<tr>
<td>World</td>
<td>7,816,544</td>
<td>100.0%</td>
<td>4,628</td>
<td>156,600</td>
<td>9,257</td>
<td>10,958</td>
</tr>
</tbody>
</table>

Table 1.8 presents the summation of grid cell totals for the four European marine areas. It shows first the total number of ship observations within each of the defined marine areas from 1992-96, along with the annual average. These figures are divided by COADS global observation totals to indicate the percentage of world ship observations made from within each of the marine areas. The results range from 3% in the case of the Baltic to 8% for North-west European waters. Together, ‘European’ waters were found to be the location for an average of 18.7% of global ship observations.

The above percentages were then applied to global fuel use and emissions estimates, as modified from Corbett et al. The results are mean annual estimates of fuel use, S, SOx and NOx for each of the marine areas. For two of the areas—the North-east Atlantic (as defined in this report) and the Mediterranean—these appear to be the first estimates of their kind.

A comparison of these estimates and others derived in a different manner can be found in Appendix 6 and in Chapter 2 (Table 2.3).
References


BMT and Plant, G. 1997 “Study on the feasibility of a mandatory discharge system of ships’ waste to shore reception facilities in ports and the financing systems of such facilities” Report for European Commission, D-G VII


ISO 8217 1996


