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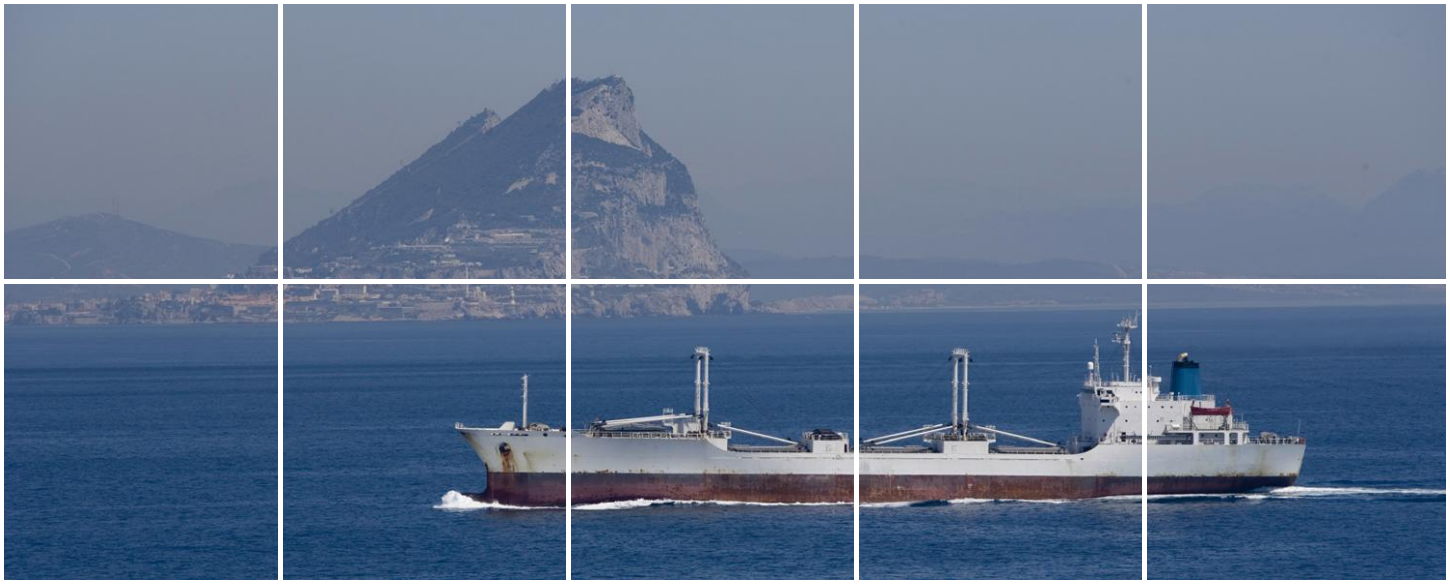

Contribution from shipping emissions to PM_{10} and nickel contents on Gibraltar

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Executive summary

Elevated concentrations of particulate matter, PM_{10} and nickel have been observed at the Rosia Road monitoring station on Gibraltar. The concentrations approach and in some cases exceed EU limit values.

Ships emit substantial quantities of particulate matter and nickel as the result of combustion of fuels while at sea, while manoeuvring and in port. The contribution from ship emissions to concentrations on Gibraltar is therefore considered in this report. Separate sections of the report consider the contributions from ships passing through the Straits of Gibraltar, ships bunkering in the Port of Gibraltar and ships using the Port of Algeciras.

The total contribution to annual mean PM_{10} concentrations from ships passing through the Straits of Gibraltar, bunkering in the Port of Gibraltar and operating from the Port of Algeciras was predicted to be 1.9 $\mu g\ m^{-3}$ at Rosia Road and 1.7 $\mu g\ m^{-3}$ at Bleak House. Of these the largest contribution comes from ships bunkering in the Port of Gibraltar. The total modelled contribution from ships, although not trivial, is relatively small compared with the total measured concentration of PM_{10} of 39.8 $\mu g\ m^{-3}$ at Rosia Road in 2006.

The total contribution to annual mean nickel concentrations from ships passing through the Straits of Gibraltar, bunkering in the Port of Gibraltar and operating from the Port of Algeciras was predicted to be 14 ng m^{-3} at Rosia Road and 13 ng m^{-3} at Bleak House. Of these the largest contribution comes from ships bunkering in the Port of Gibraltar. The measured concentration of nickel at Rosia Road was 17.6 ng m^{-3} in 2005, 15.8 ng m^{-3} in 2006 and 17.1 ng m^{-3} in 2007. The measured nickel concentration was slightly higher in 2008 at 20.4 ng m^{-3} in 2008, although this was influenced by one month's high measurement. The total modelled contribution from ships thus makes up a substantial part of the measured nickel concentration.

The predicted concentrations of PM_{10} and nickel are affected by several sources of uncertainty. These include:

- The estimates of fuel consumption by ships while at sea, manoeuvring, in port and while transferring oil into bunkers;
- The estimates of emission factors for PM_{10} and the nickel content of fuels;
- The estimates of the discharge conditions affecting plume rise from ships;
- The effect of the Rock on meteorological conditions.

Further work to improve the estimates of fuel consumption and the nickel content of fuels is likely to result in the greatest reduction in uncertainty.

Table of contents

1 Introduction

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Ships emit substantial quantities of particulate matter and nickel as the result of combustion of fuels while at sea, while manoeuvring and in port. The contribution from ship emissions to concentrations on Gibraltar is therefore considered in this report.

In Section 2 of the report, the contribution from ships travelling through the Straits of Gibraltar is considered. Section 3 considers the contribution from ships bunkering in the Port of Gibraltar. Section 4 considers the contribution from ships using the port of Algeciras.

2 Ships travelling through the Straits of Gibraltar

2.1 Introduction

The Straits of Gibraltar provides the only access for shipping to the Mediterranean Sea from the Atlantic Ocean. The Straits thus provide a major shipping route with approximately 80,000 shipping movements per year. A proportion of the ships refuel using the bunkering facilities at Gibraltar or load or unload cargoes from ports on the Bay of Gibraltar: these are considered elsewhere in this report. The remaining ships travel past Gibraltar on the major shipping lanes 10-15 km south of Gibraltar. The contribution from these remaining ships to PM_{10} and nickel concentrations in Gibraltar is considered in this section.

2.2 Emissions

Entec UK Ltd prepared a report for the European Commission "Quantification of emissions from ships associated with ship movements between ports in the European Community". Entec analysed data supplied by Lloyds Marine Intelligence Unit (LMIU) on the movements of ships in 2000. They then applied emission factors to the ship activity data to provide spatially disaggregated estimates of pollutant emissions from ships. The Entec report indicates that the emission of sulphur dioxide from the 50 x 50 km area including the Straits of Gibraltar was approximately 5000 tonnes per year.

The emission factors used in the Entec report for sulphur dioxide were in the range 9.8-12.9 g/kWh. Particulate emissions for ships at sea are typically 1.2 g/kWh (Entec 2005). It is thus estimated pro-rata that the particulate emissions from ships in the 50 km square including the Straits of Gibraltar were approximately 550 tonnes per year.

For this analysis, it has been assumed that these emissions are concentrated along the main shipping lane into and out of the Mediterranean Sea. It is thus estimated that the average rate of emission of particulate matter was 550/50=11 tonnes per km per year along the shipping lane.

The rate of nickel emissions from ships depends on the nickel content of the fuel oil. The nickel content depends on the source of the fuel. The nickel content of heavy fuel oils used for a US EPA research programme[1] was in the range 17-34 μg/g. The nickel content of heavy fuel oils in the Environment Canada Oil Properties database[2] was 37 μg/g or less. For this assessment, it has been assumed that 50 μg/g provides a conservative overestimate of nickel contents. It has also been assumed that the ships have a specific fuel consumption of 223 g/kWh. On this basis, it was estimated that the average rate of emission of nickel was 0.1 tonnes per km per year along the shipping lane.

2.3 Dispersion modelling

The dispersion model ADMS4.1 was used to predict the concentration of particulate matter and nickel at the monitoring stations at Rosia Road and Bleak House on Gibraltar. A dispersion model ADMS-4.1 was used to predict ground level concentrations of oxides of nitrogen, carbon monoxide and sulphur dioxide. ADMS-4.1 is a PC-based model of the dispersion in the atmosphere of passive, buoyant or slightly dense continuous or finite duration releases from single or multiple sources. It is a state of the art dispersion model in which the boundary layer structure is characterised by the height of the boundary layer and the Monin-Obukhov length, a length scale dependent on the friction velocity and heat flux at the surface. Concentration distributions are Gaussian in stable and neutral conditions, but the vertical distribution is non-Gaussian in convective conditions to take account of the skewed structure of the vertical component of turbulence. The model contains a meteorological preprocessor that calculates the required boundary layer parameters from a variety of meteorological input data. The model can be used to calculate mean concentrations and concentration percentiles for averaging

[1] Primary Particles Generated by the Combustion of Heavy Fuel Oil and Coal. http://www.epa.gov/appcdwww/aptb/EPA-600-R-02-093.pdf
[2] http://www.etc-cte.ec.gc.ca/databases/OilProperties/

times ranging from seconds to a year. The model contains modules for predicting the influence of plume rise, terrain and buildings on dispersion.

The ship emissions were represented as a sea-level line source extending from 36^{o} 08' 37"N 5^{o} 03' 14"W to 35^{o} 52' 56"N 5^{o} 45' 42"W and 1000 m wide.

Hourly sequential meteorological data fro Gibraltar airport was used to represent weather conditions. The surface roughness of the sea was assumed to be 0.001 m.

2.4 Results

Table 1 shows the predicted contribution to annual mean concentrations from ships in the Straits of Gibraltar to PM_{10} and nickel concentrations at the Rosia Road and Bleak House monitoring sites.

Table 1: Predicted contribution from ships passing through the Straits of Gibraltar to annual mean concentrations

	Contribution to PM_{10} concentration, $\mu g\ m^{-3}$			Nickel contribution, $ng\ m^{-3}$		
Met. data year	2006	2005	2004	2006	2005	2004
Site						
Rosia Road	0.28	0.25	0.25	2.5	2.2	2.2
Bleak House	0.37	0.34	0.34	3.4	3.1	3.1

3 Bunkering ships off Gibraltar

3.1 Introduction

Gibraltar is the one of the largest bunkering ports in the Mediterranean. 4.3 million tonnes of fuel were delivered to ships bunkers in 2007 and bunkering is now the main activity within the Port of Gibraltar. Of a total of 8,351 deep-sea vessels that called at Gibraltar in 2007, 5,640 were supplied with bunkers.

Bunkers are normally delivered by barge while the vessel is at anchor in Bay of Gibraltar – but they can also be delivered at berth in the harbour, for example for cruise ships. The engines on the barges and the vessels emit particulate matter, PM_{10} and nickel throughout the period that the vessels and barges are at anchor.

The contribution to particulate and nickel concentrations resulting from bunkering activities is considered in this section.

3.2 Emissions

The Environmental Agency provided details of bunkering activities over the period 14/08/07-14/09/07. Details were provided of the quantities of fuel transferred at each of the main anchor positions. The fuel used to pump the fuel between the barge and the receiving ship was estimated using a factor of 0.7 kg fuel per tonne of fuel transferred[3]. The emissions of PM_{10} were then estimated based on an emission factor of 9.6 kg/tonne appropriate for oil ships in port from the Entec report[4]. Emissions of nickel were estimated assuming a nickel content of the fuel oil of 50 μg/g. The average rate of emission was then calculated over the 31day period.

Details of ships bunkering were obtained from the Port of Gibraltar shipping movements log[5] for the period 16/05/2009-16/06/2009. The log provided details of the gross tonnage of each ship and the duration it stayed in port/at anchor. The fuel consumption of each ship while in port was estimated using an empirical equation appropriate for general cargo ships taken from the Trozzi and Vaccarro report:

$$C = 0.12.\frac{n}{24}.(16.623 + 0.001GT)$$

.

where C is the fuel consumption in tonnes
n is the duration in port, hours
GT is the gross tonnage of the ship.

The emission of PM_{10} was then estimated from the fuel consumption using an emission factor of 6.5 kg/tonne appropriate for general cargo taken from the Entec report. Emissions of nickel were estimated assuming a nickel content of the fuel oil of 50 μg/g. The average rate of emission was then calculated over the 31day period.

The total emissions of PM_{10} and nickel were allocated to each of the anchor positions in proportion to the fuel transferred over the period 14/08/07-14/09/07.

[3] C Trozzi R Vaccarro. Methodologies for estimating air pollutant emissions from ships. Techne Report MEET RF98. http://www.inrets.fr/infos/cost319/MEETdeliverable19.pdf

[4] http://ec.europa.eu/environment/air/pdf/chapter2_ship_emissions.pdf

[5] http://www.gibraltarport.com/shipping_movements.cfm

Details of cruise ships staying in port were obtained from the 2008 cruise schedule[6]. The cruise schedule provided details of the name of each ship, the passenger capacity and the duration of stay. The gross tonnage of a selection (25) of the named ships was obtained from various internet sources and a statistical relationship determined between gross tonnage (GT tonnes) and passenger capacity (P):

GT=35.3. P

The fuel consumption of each cruise ship while in port was estimated using an empirical equation taken from the Trozzi and Vaccarro report appropriate for passenger ships:

$$C = 0.32.\frac{n}{24}.(16.9 + 0.002GT)$$

.

where C is the fuel consumption in tonnes
n is the duration in port, hours
GT is the gross tonnage of the ship.

The emission of PM_{10} was then estimated from the fuel consumption using an emission factor of 7.7 kg/tonne appropriate for passenger ships taken from the Entec report. Emissions of nickel were estimated assuming a nickel content of the fuel oil of 50 μg/g. The average rate of emission was then calculated over the year. The total emissions of PM_{10} and nickel were allocated to the cruise berth on the Western Arm.

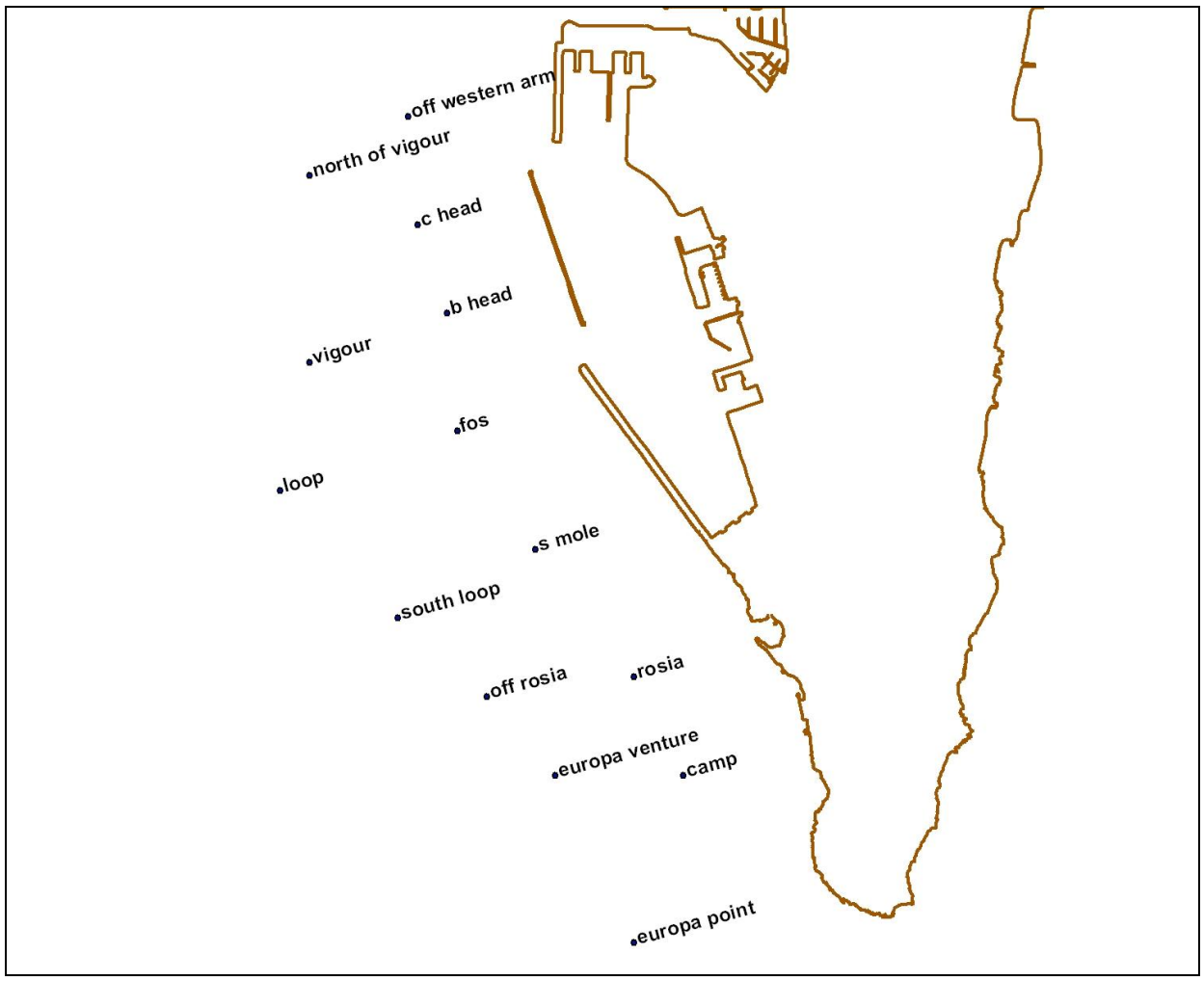
The emissions were represented as point sources corresponding to the main anchoring points. The locations of the anchor points are shown in Fig. 1. The rates of emission are shown in Table 2.

Table 2: Average rates of particulate matter and nickel emission from anchor points

Anchor point	Emission rate, g s^{-1}	
	PM_{10}	Nickel
Cruise	0.07	0.0005
Europa point	0.54	0.0039
Camp	0.21	0.0015
Europa Venture	0.32	0.0023
Rosia	0.22	0.0015
Off Rosia	0.11	0.0008
South loop	0.49	0.0035
S Mole	0.28	0.0020
Loop	0.64	0.0046
Fos	0.12	0.0009
Vigour	0.48	0.0035
B Head	0.20	0.0015
C Head	0.10	0.0007
North of Vigour	0.06	0.0005
Western Arm	0.13	0.0010

[6] http://www.gibraltarport.com/cruise/cruisesummarytotal_2008.cfm

Fig. 1: Anchor points used for bunkering



3.3 Dispersion modelling

The dispersion model ADMS4.1 was used to predict the concentration of particulate matter and nickel at the monitoring stations at Rosia Road and Bleak House on Gibraltar. Ships at anchor were represented as point sources 20 m high. It was assumed that plume rise following emission was minimal. Hourly sequential meteorological data fro Gibraltar airport for 2006 was used to represent weather conditions. The surface roughness of the sea was assumed to be 0.001 m.

3.4 Results

Fig. 2 shows the predicted contribution to annual mean particulate matter, PM_{10} concentrations from bunkering activities off Gibraltar. Fig. 3 shows the predicted contribution to annual mean nickel concentrations. The predicted contribution to PM_{10} concentrations was 1.1 $\mu g\ m^{-3}$ at the Rosia Road monitoring site and 0.8 $\mu g\ m^{-3}$ at the Bleak House monitoring site. The predicted contribution to annual average nickel concentrations was 8 $ng\ m^{-3}$ at the Rosia Road monitoring site and 6 $ng\ m^{-3}$ at the Bleak House monitoring site.

Fig. 2: Predicted contribution to annual mean particulate matter, PM_{10} concentrations from bunkering activities off Gibraltar

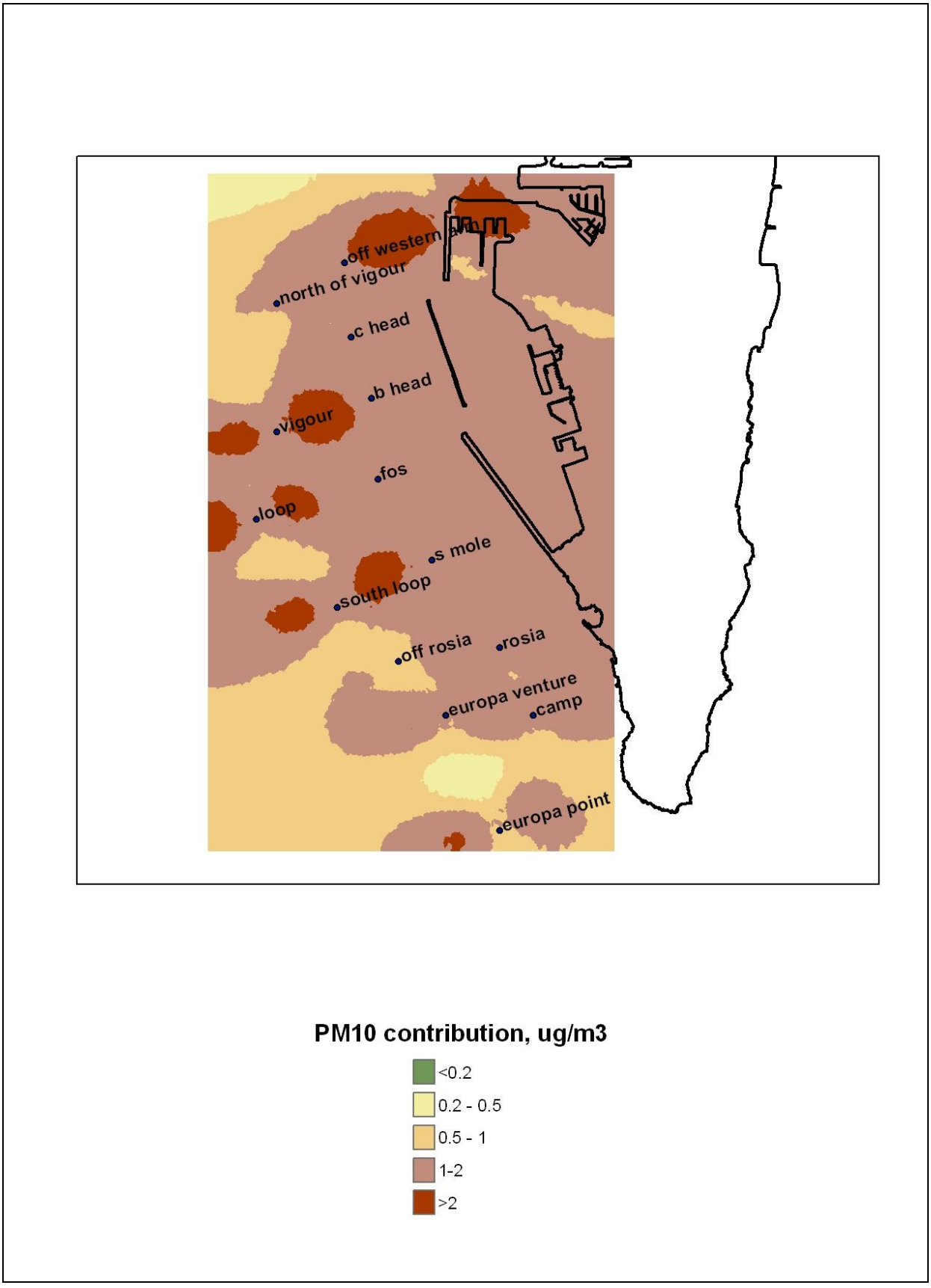
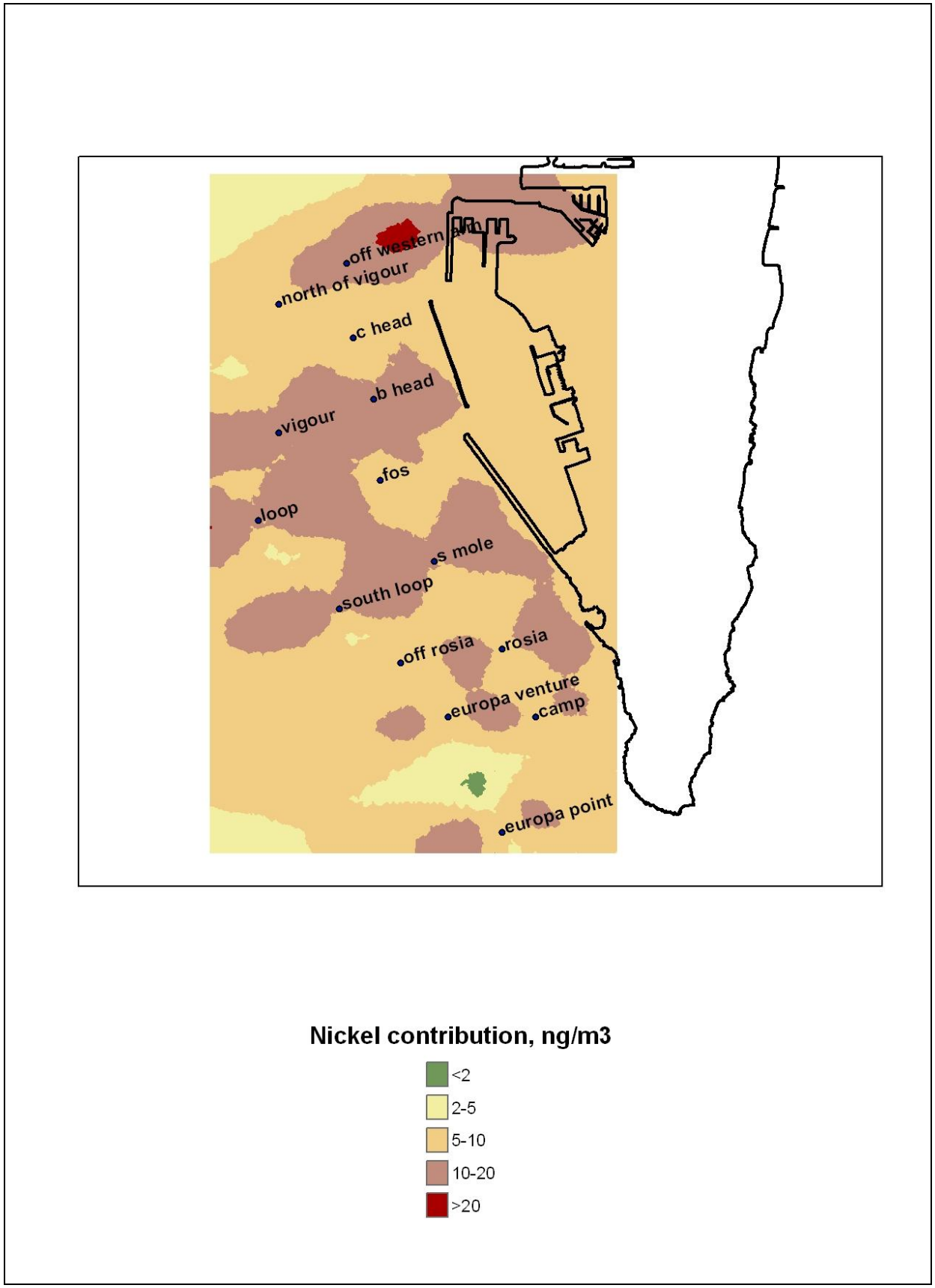


Fig. 3: Predicted contribution to annual mean nickel concentrations from bunkering activities off Gibraltar



4 Port of Algeciras

4.1 Introduction

The Port of Algeciras is Spain's largest port. Ten ferry lines connect it with North Africa operating both Ro-Ro ferries and increasingly, high speed ships. Passenger traffic was more than 5 million in 2008, with more than 1.5 million vehicles including more than 200,000 goods vehicles. Container traffic exceeded 3 million twenty-foot equivalent units (TEUs). Liquid bulk handling facilities serve the CEPSA refinery and associated petrochemical works. Solid bulk carriers deliver coal and other materials to the Endesa power station and the Acerinox steel works.

The contributions to particulate and nickel concentrations resulting from shipping activities at the port are considered in this section.

4.2 Emissions

The Port of Algeciras Annual Report for 2007 provided details of the numbers of various types of ship accessing the port and the total gross tonnage as shown in Table 3. The average gross tonnage for each ship type was then calculated by dividing the total gross tonnage y the number of ships for each class. Empirical relationships taken from the Trozzi and Vaccaro report were then used to calculate average fuel consumption for each class of ship while at sea, while manoeuvring into port and while in port.

Table 3: Numbers and gross tonnage of ships and estimated rates of fuel consumption per ship

Type of ship	Number	Gross tonnage	AverageGT per ship	Fuel consumption, tonnes per day		
				At sea	Manoeuvring	In port
Tankers	1910	38902552	20367.83	24.6	12.3	6.2
Bulk carriers	378	9573023	25325.46	26.1	13.0	3.9
General cargo	523	3683132	7042.317	15.9	8.0	2.4
Ro Ro	711	4602582	6473.392	18.3	9.2	7.3
Passenger	19469	129813023	6667.678	24.1	12.0	9.6
Container	1942	62027179	31939.85	66.5	33.2	10.0
Other merchant ships	1364	13442508	9855.211	19.1	9.6	2.9

Rates of emission of PM_{10} were then estimated from the fuel consumption using emission factors for each type of vessel taken from the Entec report. The Entec report also provided estimates of the time spent in port by each ship type and the speed attained by the ship types at sea. These data were then used to calculate the average emission per ship visit while manoeuvring and while in port and the emission per ship-km for ships at sea as shown in Table 4. Nickel emissions were similarly calculated based on a nickel content of the fuel oil of 50 μg/g.

Table 4: Calculation of PM_{10} emissions per ship visit.

Type of ship	PM_{10} emission rate per ship, kg day^{-1}			Time in mode, hours		Speed at sea, kph	Emission per ship visit, kg		Emission per ship-km at sea, kg
	At sea	Manoeuvring	In port	Manoeuvring	In port		Manoeuvring	In port	
Tankers	136	68	59	1.5	47	26	4.24	115.72	0.22
Bulk carriers	144	72	27	1	52	26.5	3.00	57.63	0.23
General cargo	88	44	16	1	38.5	22.8	1.83	24.89	0.16
Ro Ro	101	51	56	1	4	28.4	2.11	9.30	0.15
Passenger	133	66	74	0.6	2	38.5	1.66	6.18	0.14
Container	367	183	67	1	14.3	35.7	7.64	39.82	0.43
Other merchant ships	106	53	19	1	38.5	22.8	2.20	29.92	0.19

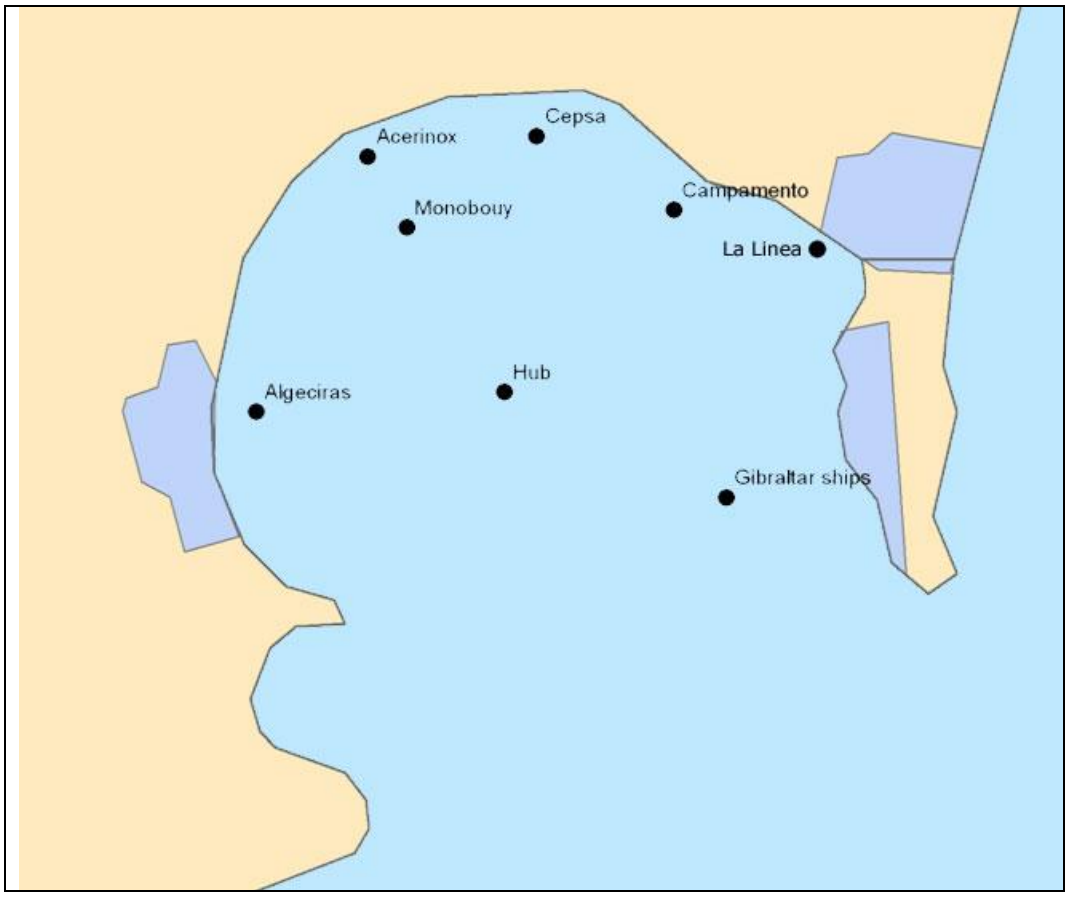
The Port of Algeciras Annual Report for 2007 also provided details of the tonnage of liquid bulk materials, dry bulk materials and general cargo and the numbers of passengers handled at the main areas of the port. These are listed in Table 5. The location of the main port areas is shown in Fig. 4 (names relate to brackets in Table 5).

Table 5: Quantities of materials and numbers of passengers

Port area	Quantities of materials, tonnes			No. of passengers
	Liquid bulk	Dry bulk	General Cargo	
Acerinox		631932	276545	
Cernaval (Campamento)			584	
Cepsa	8961328		2939	
Monobuoy	9731373			
Campamento		48705	14106	
Norte (Cepsa)	821178		218075	
Endesa (Acerinox)		1529650	333	
Galera (Algeciras)			3934176	4148353
Isla Verde (Algeciras)		469565	3990288	
Juan Carlos (Algeciras)	188		38305271	
Principe Felipe (Algeciras)			429423	
La Linea			10500	
Tarifa			3027	1076570

The number of ships in each class and the emissions shown in Table 4 were then allocated to each of the port areas in proportion to the numbers of passengers or tonnage of materials. All container in-port and manoeuvring emissions were allocated to the Juan Carlos and Principe Felipe port areas. The total nickel emissions were allocated in proportion to the PM_{10} emissions. It was then assumed that ships travel at sea to and from a central point in the bay (Hub) in transit to destinations outside the bay.

Fig. 4: Algeciras port areas



4.3 Dispersion modelling

The dispersion model ADMS4.1 was used to predict the concentration of particulate matter and nickel at the monitoring stations at Rosia Road and Bleak House on Gibraltar. Ships at anchor were represented as point sources 30 m high. Ships at sea were represented as line sources. It was assumed that plume rise following emission was minimal. Hourly sequential meteorological data fro Gibraltar airport for 2006 was used to represent weather conditions. The surface roughness of the sea was assumed to be 0.001 m.

4.4 Results

Fig. 5 shows the predicted contribution to annual mean particulate matter, PM_{10} concentrations from shipping activities in the Port of Algeciras. Fig. 6 shows the predicted contribution to annual mean nickel concentrations. The predicted contribution to PM_{10} concentrations was 0.6 $\mu g\ m^{-3}$ at the Rosia Road monitoring site and 0.5 $\mu g\ m^{-3}$ at the Bleak House monitoring site. The predicted contribution to PM_{10} concentrations was 3.8 ng m^{-3} at the Rosia Road monitoring site and 3.3 ng m^{-3} at the Bleak House monitoring site.

Fig. 5: Predicted contribution to annual mean particulate matter, PM_{10} concentrations from activities at the port of Algeciras

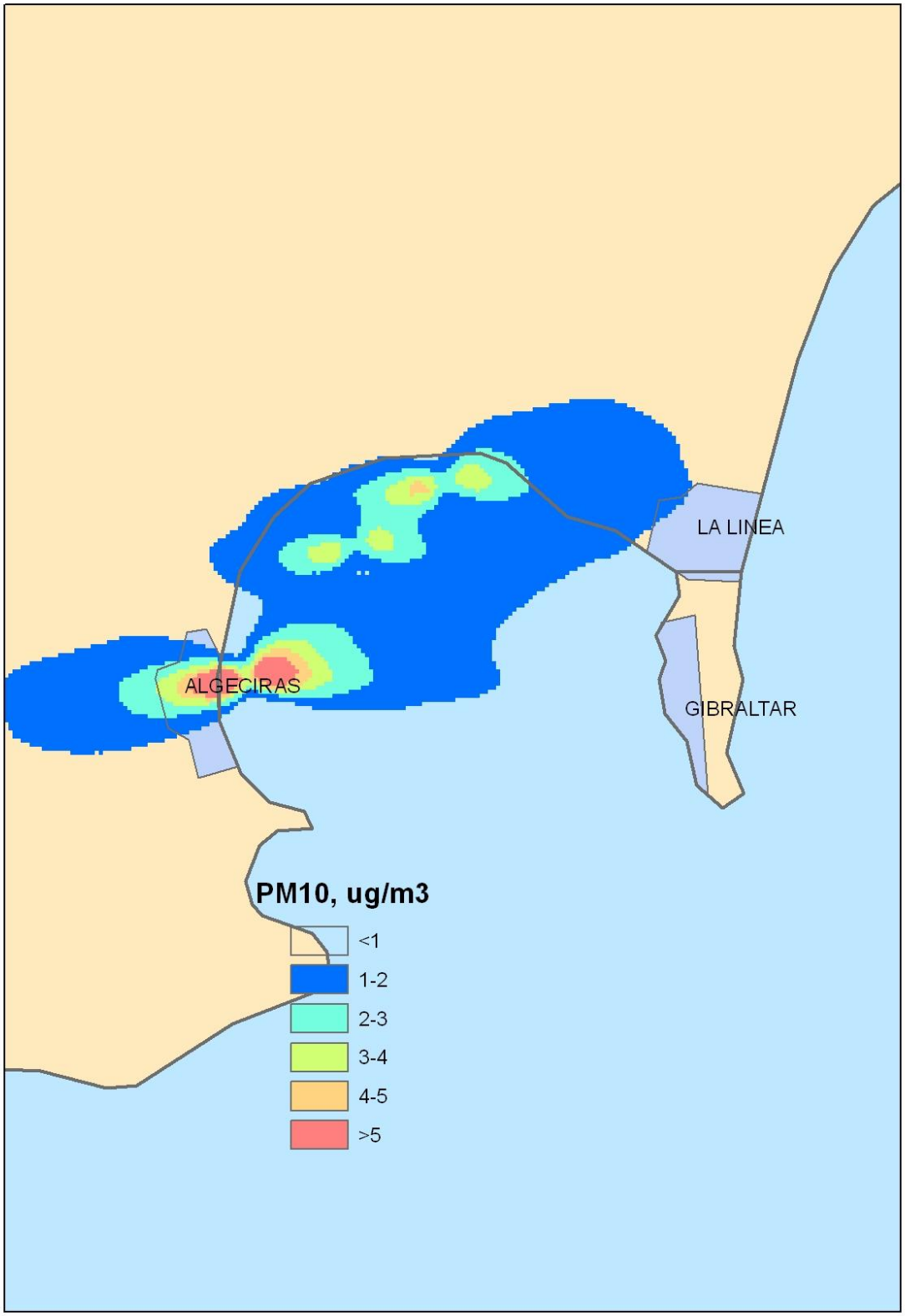
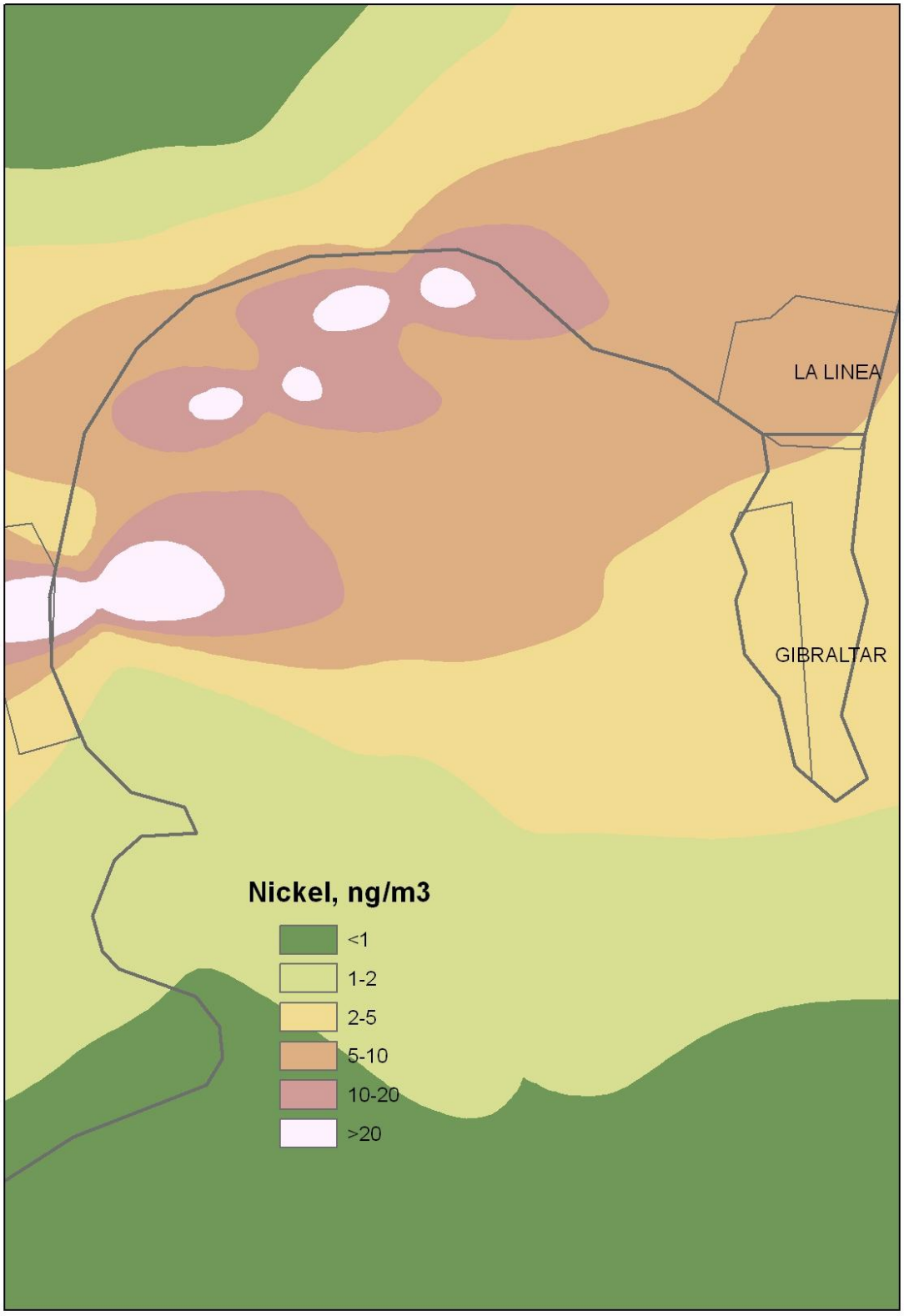


Fig. 6: Predicted contribution to annual mean nickel concentrations from activities at the port of Algeciras



5 Summary

The total contribution to annual mean PM_{10} concentrations from ships passing through the Straits of Gibraltar, bunkering in the Port of Gibraltar and operating from the Port of Algeciras was predicted to be 1.9 $\mu g\ m^{-3}$ at Rosia Road and 1.7 $\mu g\ m^{-3}$ at Bleak House. Of these the largest contribution comes from ships bunkering in the Port of Gibraltar. The total modelled contribution from ships, although not trivial, is relatively small compared with the total measured concentration of PM_{10} of 39.8 $\mu g\ m^{-3}$ at Rosia Road in 2006.

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The predicted concentrations of PM_{10} and nickel are affected by several sources of uncertainty. These include:

- The estimates of fuel consumption by ships while at sea, manoeuvring, in port and while transferring oil into bunkers;
- The estimates of emission factors for PM_{10} and the nickel content of fuels;
- The estimates of the discharge conditions affecting plume rise from ships;
- The effect of the Rock on meteorological conditions.

Further work to improve the estimates of fuel consumption and the nickel content of fuels is likely to result in the greatest reduction in uncertainty.

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