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Quantitative assessment of the development of the offshore oil and gas industry in the North Sea

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An overview is given of the development of the offshore oil and gas industry in the North Sea and the possible physical impact on the ecosystem in the short and long term. The order of magnitude of several activities (seismic exploration, drilling, platforms, pipelines, subsea facilities, and gas flaring) has been estimated on the basis of information from national authorities and the hydrocarbon industry.

Key words: drilling, hydrocarbon industry, North Sea, pipelines, seismic exploration.

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Introduction

The exploitation of oil and gas in marine areas dates back to the mid-1930s. With the rapid advancement of new technology, the offshore hydrocarbon industry spread around the world, and even more remote and less accessible resources have been explored. The industry reached the North Sea in the 1960s and the first wells were drilled in the Dutch sector in 1961 (Chapman, 1976). Denmark first handed out licences in 1963, followed by the United Kingdom and Germany in 1964 (Arnold, 1978).

The exploitation of hydrocarbon resources can be split into four phases, which are characterized by considerable differences in terms of impact on the marine ecosystem: (1) surveying of reserves based on seismic evaluation of geological formations; (2) exploratory drilling of wells to confirm the prospective accumulation of hydrocarbons; (3) additional drilling to appraise the extent and volume of an established reservoir; and (4) commercial production of oil and gas requiring the development of a large infrastructure to transport the material to land stations.

British Petroleum struck gas in the North Sea in 1965, followed soon by Shell Expro finding the large Leman Bank gas field. In the Dutch sector, gas was first located by Placid International Oil and an exploitation licence was handed out in 1971. The first oil reserve was found in the Danish sector in 1967, followed by Norway in 1969, when the extensive Ekofisk field was located. This field came on stream in 1971. Frigg field was discovered in 1971 and commenced production 6 years later. The giant Statfjord field was discovered in 1974. In the Dutch sector oil was first found in 1970 and brought ashore in 1982 by Union Oil.

To date, an enormous network of interconnected platforms and pipelines exists (see Figure 1.10 in North Sea Task Force, 1993). The total production in 1992 was about 92.5×10^9 m^3 of gas and 183×10^6 t of oil. Many studies have addressed the specific impact that particular offshore activities (seismic exploration, drilling muds, artificial reef function of platforms, gas flaring, etc.) may have on various components of the ecosystem. However, it is difficult to evaluate the impact of the entire industry, because an integrated quantitative overview of the development of different activities over the years is not available. Although such information should exist within individual companies or nations, there is no integrated information available for the whole North Sea.

This article presents a first attempt to quantify the development of a range of activities related to the oil and gas industry in the North Sea as a basis for future comparison with observed trends in various components of the ecosystem. The measures considered refer to seismic and drilling activities, platforms, pipelines, subsea facilities, and gas flaring and reflect the physical impact on the system.

Sources of physical impact

Seismic surveying

Two main seismic surveying techniques are used in the offshore industry (Greene and Richardson, 1988). The two-dimensional (2-D) seismic technique is based on line

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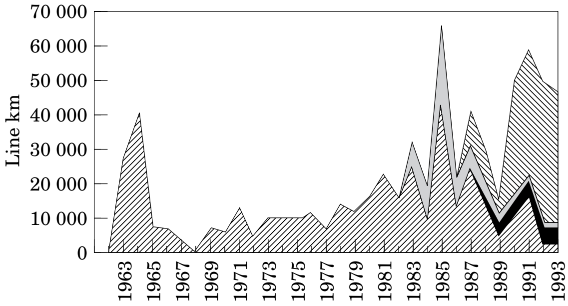

Figure 1. Amount of 2-D and 3-D seismic (line km) shooting on the continental shelf of The Netherlands (1963–1993; Anon., 1994a) and Denmark (1983–1993; Anon., 1994b). (▧=D-3D, ▩=D-2D, ■=NL-3D, ▨=NL-2D).

transects and has the longest tradition. Since the mid-1980s, a three-dimensional (3-D) technique has been introduced yielding a more comprehensive picture of the available resources and gradually superseding the 2-D technique. However, the acquisition technique is largely the same, shooting lines being only more closely spaced. The impact per line km depends largely on airgun volume, pressure, and shot rate.

Thus, the effects of the two methods are similar and include physical damage and disturbance of marine mammals (Van Dessel, 1991) and of fish. Physical damage, particularly rupture of swimbladders, may ultimately cause death (Engås *et al.*, 1993). Disturbance effects are limited to relatively small areas and are essentially short term.

Large parts of the bottom have been investigated with 2-D, but all areas having a potential for undiscovered oil and gas reserves have been, or are likely to be, re-investigated with 3-D techniques. It is expected that areas once investigated with 3-D will generally not be surveyed again because, even when companies obtain rights over such an area, it is cheaper to buy existing information than to repeat the survey. Hence, seismic surveying will probably be stopped once all relevant areas have all been thoroughly investigated.

Figure 1 shows the distance surveyed in the Dutch and Danish sectors by the two techniques. Top years for The Netherlands were 1964 and 1985. In recent years, 2-D surveying has decreased in both countries, while 3-D surveying has increased.

Seismic surveying in the Norwegian sector started in 1962 and by 1993 a cumulative total of 1 622 822 km had been shot south of 62°N. In 1993, 261 492 km were shot, of which more than 90% were 3-D (Anon., 1994c). Annual information is not available over the entire period. No details are given for the UK sector by the available sources (Anon., 1994d).

Drilling

Distinction is generally made between exploration, appraisal, and production wells, which differ in terms of diameter of the bore hole and therefore are associated with different amounts of cuttings. Figure 2 shows the annual number of wells by category drilled by different countries. The UK (Fig. 2a) has put in by far the most effort (Anon., 1994d). These data exclude areas west of Shetland and outside the North Sea. Drilling for exploration and appraisal has followed a cyclical pattern with a generally increasing trend. In recent years, activities appear to have been relatively low. Drilling for production wells has remained rather more constant at a high level since the extension in the late 1960s. In total, 1530 exploration, 997 appraisal, and 2256 production wells have been drilled over the period 1964–1993 (based on national reports).

The Netherlands (Fig. 2b) drilled 559 exploration, 114 appraisal, and 314 production wells during the period 1962–1993 (Anon., 1994a). Of the exploration wells, 367 were dry, 116 contained gas, 24 oil and 2 both gas and oil. Of the appraisal wells, 37 were dry, 54 contained gas, 22 oil and 1 both. The effort has been fairly stable over most of the period.

Danish data (Fig. 2c) are available only since 1983 (Anon., 1994b). Over 150 exploration wells (including coastal waters) have been drilled over these years, but the activity has gradually decreased since the mid-1980s. Appraisal wells largely follow the same pattern. In contrast, drilling for production wells increased to a maximum of 32 in 1993. Of these, only two were drilled in a conventional way, whereas all others were driled horizontally. The total number of horizontal wells in operation is at present 69 and is expected to increase further.

Norway distinguishes wells differently. In this sector, 726 exploration wells had been completed by the end of 1993 (Fig. 2d), of which 45 were temporarily abandoned. Of the total of 771 wells, 549 were wildcats and 222 contained oil or gas ("appraisal wells").

Only a small number of wells have been drilled in the German sector. Gas was found at two locations, but production has not started nor is it considered in the near future. Oil has been found near the Danish Rolf-field in the northern part, but the reserves do not warrant exploitation (pers. comm. K. Figge, BSH, Hamburg).

Figure 3 combines the available time series into one figure for the total North Sea by country. During a drilling operation for oil, which is found typically at a depth of ca. 4000–5000 m below the sea bed, an average of 1000 m^3 of cuttings are produced per well (Dicks *et al.*, 1986/1987). Thus, a total number of 6921 wells drilled throughout the period 1964–1993 would correspond to approximately 7 million m^3 of cuttings dumped

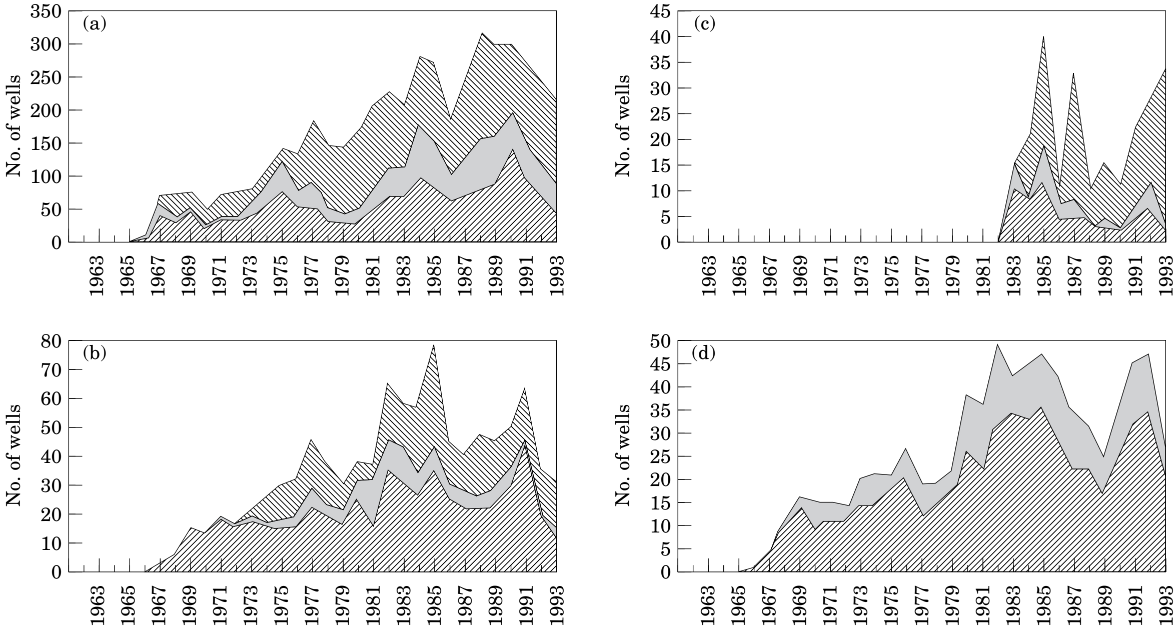

Figure 2. Number of exploration (▧), evaluation (□) and production (▨) wells drilled on the continental shelf by: (a). United Kingdom: 1963–1993 (Anon., 1994d); (b). The Netherlands: 1965–1993 (Anon., 1994a); (c). Denmark: 1983–1993 (Anon., 1994b); (d). Norway: 1964–1993 (Anon., 1994c).

on the seabed. Depending on discharge practices (close to the seabed or at the surface), cuttings may smother benthic life around the platform, but a thin layer may be found within a radius of 400–1000 m around a well and even affect larger areas, depending on whether oil-based or water-based muds are produced (Davies *et al.*, 1984; Leaver *et al.*, 1987; Kingston, 1990). It is still unclear how long it takes for the cutting piles to become totally eroded by wave action and tidal currents (Dicks *et al.*, 1986/1987). Since drilling depths vary with location, a better measure of the physical impact might be the distance drilled. Such data are given for the Dutch sector in Figure 4 (Anon., 1994a).

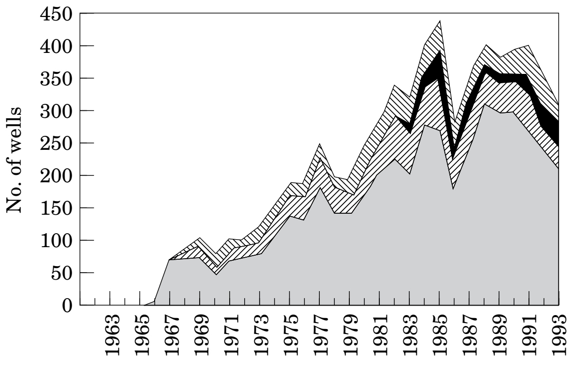

Figure 3. Total number of wells drilled in the North Sea by country. (▧=Norway, ■=Denmark, ▨=Netherlands, □=UK).

Platforms

Platforms act as artificial reefs and may thus affect the local benthos and fish communities. In addition, exploitation platforms are surrounded by a safety zone of 500 m, restricting other human activities such as fishing. Effects are essentially short term and last for the duration of their presence. Side *et al.* (1993) reviewed the existing controls for abandonment and disposal of offshore installations at sea. There is another potential long-term effect, because platforms are moved worldwide and non-indigenous species may be introduced as they travel with the fouling. However, such impact must be viewed against the re-distribution of biota caused by overall shipping activities.

Platforms vary widely in size and type and are often classified in the statistics. However, information varies considerably and a coherent picture of the total scale of the constructions and of the development over time cannot easily be obtained. Data are given here only for the situation in 1993.

A total of 121 platforms were situated in the Dutch sector and 4 had been removed. They included 18 production, 20 integrated, 40 satellite, 40 compression and 3 accommodation platforms. In addition, there were 21 well heads, 6 subsea completion stations, and 1 offshore loading tower (Anon., 1994a). The 29 platforms present in the Danish sector in 1993 included 12 well heads, 5 processing/accommodation, 1 riser, 1 riser/booster, and 1 well head/processing/booster platform,

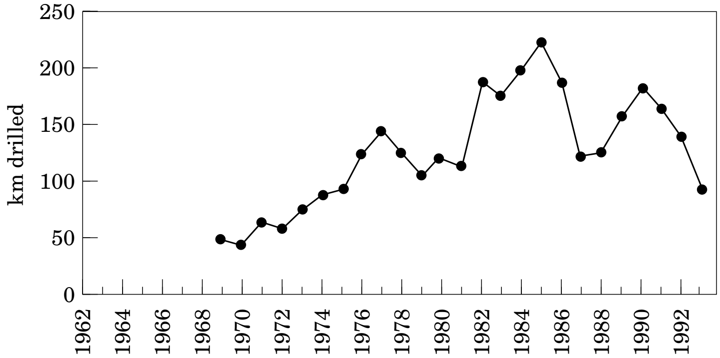

Figure 4. Total distance (km) drilled through the bottom on The Netherlands continental shelf for exploration and production 1969–1993 (Anon., 1994a).

Table 1. Pipeline length in miles by pipe diameter (cm) and by material conveyed in the UK sector. (Anon., 1994d).

Material conveyed:	Diameter															Total
	36	34	32	30	28	24	20	18	16	14	12	10	8	6	<6	
Crude oil	304	220	—	253	—	246	19	5	163	63	73	19	78	42	4	1489
Associated gas	281	—	—	—	—	—	229	45	59	—	—	25	22	20	7	688
Natural gas	404	—	443	671	87	434	86	19	139	7	72	25	39	1	10	2549
Condensate	—	—	—	—	—	—	—	9	—	39	—	—	60	6	—	114
Total	989	220	443	924	87	680	334	78	361	109	145	69	199	69	21	4840

5 gas flare stacks, and 4 storage caissons (Anon., 1994b; North Sea Task Force, 1993). In the UK sector, 62 oil production platforms were in operation and 5 were under construction (Anon., 1994d). No detailed information is available on the scale of the constructions in the Norwegian sector (Anon., 1994c).

Pipelines

Pipelines probably have a minor effect on the environment, even when the network expands in future. Disturbance of the seabed is restricted to the time of laying and depends on the burial techniques used. Although pipelines will be cleaned before abandonment and sea water will be let in, the reality is that they will stay in place after use. It may take hundreds of years before they have corroded in their concrete coatings (Van Dongen, 1983; De Groot, 1982, 1986; IJlstra, 1989).

Pipelines represent the cheapest and safest means of transporting oil and gas from offshore production facilities to onshore locations. Buried pipes are often preferable to those exposed on the seabed, because the latter are subject to damage from direct lift and drag forces of waves, erosion under the structure, damage from ship anchors and unstable bottoms (de Waal, 1982). If the diameter is less than 45 cm (18″), the pipe should be buried under a soil cover of at least 0.2 m. Larger diameter pipes may be positioned on the seabed, provided they are outside sensitive areas.

A wide variety in pipe diameters is being used. Smaller pipes, often only made of steel or coated with polyethylene, are used for interfield lines. Larger diameters serve for trunk pipelines. To increase weight and resistance against the impact of fishing gears, these steel pipes are covered with iron cage constructions embedded in a mix of concrete and iron ore. There are no safety zones along pipeline routes.

From 1974 to 1993, 1702 km of pipeline was laid in the Dutch sector. The main pipelines in the Danish sector, one for oil and one for gas, stretch over a total distance of 450 km. These figures exclude 450 km of ZEEPIPE-I in the Dutch and 18 km in the Danish sector, respectively (Ekofisk–Zeebrugge) runs also for 18 km through the German and for 30 km through the Belgian sector. The German sector is further crossed by 350 km of EUROPIPE-I (Ekofisk–Emden).

Pipe-laying started in the UK sector in 1970 on the Indefatigable–Leman Bank. By 1993, 139 pipelines with a total length of 4840 km had been laid and 10 pipelines were awaiting commission or under construction. A breakdown by pipe diameter and type of material conveyed (Anon., 1994) is given in Table 1.

The Norwegian pipeline system is the most extensive in the North Sea. All Norwegian oil and gas fields are interconnected and also connected to onshore locations in other countries. Although the exact length could not be traced, the main lines, including NORPIPE, FRIGG, FROST, STATPIPE, ZEEPIPE-I, EUROPIPE-I, SLEIPNER ØST, and OSEBERG TRANSPORT SYSTEM, and varying in diameter between 45 and 100 cm, represent approximately 4000 km. Several large pipeline systems are presently (1996) under construction or in an advanced stage of planning. Important future developments are EUROPIPE-II (Ekofisk–Emden) and NORFRAC (Ekofisk–Dunkirk), which will run parallel to existing pipelines (Anon., 1994c).

Subsea facilities

Apart from visible platforms, a variety of installations may be placed directly on the seabed, acting as artificial reefs and attracting fish. They are well protected against damage caused by fisheries and indicated on charts. There is no legislation to enforce removal after use and corrosion will take hundreds of years.

The installations range from satellite wells, units where the flows from different satellite wells are merged and directed to processing platforms, storage facilities, compression stations, to simple protection devices for suspended well heads. The larger subsea facilities have the status of a production platform and are surrounded by safety zones. Abandoned well heads have no safety zone. Their number is expected to increase until it becomes economically attractive to exploit even the smaller reserves.

Gas flaring

Gas flaring is one of the short-term side effects of oil production and causes problems to bird migration (Sage, 1979; Avery *et al.*, 1980). Production licences stipulate that surplus gas may be burned at sea only with the consent of the authorities. In principle, gas should be re-injected into the bottom, or stored in reservoirs for later transport ashore. Nevertheless, an average of 6–8 million m^3 is burned daily in the UK sector. The daily amount per oil field varies between 0 and 0·44 million m^3.

Discussion

There is a vast amount of detailed information available in governmental reports as well as in reports from the industry. However, the kind of information provided by different countries and the confidentiality of concern reports make it very difficult to extract a coherent picture of the total physical impact of the oil and gas industry. Nevertheless, integrating quantitative information about the development of the industry on a North Sea wide scale is a prerequisite before the impact on the marine ecosystem can be evaluated. This study must be seen as a step in that direction.

The extent of seismic surveys in the past is fairly well established, at least in some sectors. Although it is difficult to estimate the direct impact on fish and mammals, a recent average of 40 000 km of 3-D surveying per year in the Danish sector alone does not seem negligible!

The number of wells drilled is well known for most sectors and, based on the average cuttings per well, a reasonable estimate can be made of the total amount dumped per year. Based on the number of production wells and the surrounding safety areas (regulations are that fishing is not allowed within 500 m), the total surface area protected against fishing may be estimated for certain regions, but this is not straightforward because there is no statistic of the number of production wells, platforms, and subsea facilities in operation at any point in time. More extensive data may be available within the industry.

Information on the extent of pipelines is also quite good, but this aspect is probably less important because of the limited impact on the ecosystem.

Gas flaring appears to have a larger impact on migrating land birds than on seabirds. Thus, an overall figure of the amount of gas burned would be less important than the number of flames during important migration seasons, particularly autumn and spring.

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