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MULTICONSULT

Report

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Subject:	**Environmental impact**
Report:	**Abandonment offshore and disposal on land**
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Summary:

This report deals with the various environmental consequences of either abandoning concrete installations offshore on the Norwegian continental shelf (NCS) or towing them to land for disposal there.

The environmental impact of abandoning concrete installations in the North Sea is limited. The biological production which currently occurs on these installations would disappear if they were removed, and the structures do not affect fish populations or fishing. If they are fitted with lights and navigation equipment, the threat of any conflict with shipping is small. Were the installations also cut down to 55 metres beneath sea level, they would not present any restrictions to shipping at all.

At the same time, the potential environmental impact of removal to land is substantial. A danger of accidents naturally exists when refloating installations and moving them to land, but the conflicts primarily relate to environmentally acceptable environmental reconstruction, demolition and intermediate waste storage. These operations are expected to involve a high risk of dispersing polluted water as well as much dust and noise.

A large amount of space would be required, both on land and in the sea, and the level of potential conflicts with neighbours is expected to be high.

In terms of energy consumption and emissions to the air, abandonment of a concrete structure at sea would be far more favourable than disposing of it on land.

From an overall perspective, therefore, offshore abandonment would clearly have the lowest environmental impact.

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Contents

1. Summary

The Norwegian sector of the North Sea contains 12 concrete installations. The present report considers the various environmental consequences of abandoning these offshore or removing them to land. It also presents possible alternatives for demolition and opportunities for recycling if an installation is removed to land.

This report falls into two parts. Chapter 3 presents an assessment of the environmental impact of abandoning concrete installations offshore, while chapter 4 assesses the impact of removal to land. Chapter 5 presents an energy and environmental account for the two alternatives. Chapter 6 provides an overall summary of the various environmental consequences.

1.1 Offshore abandonment of concrete installations

Every artificial structure, including a concrete installation, which sticks up from the seabed will function as an artificial reef. That applies both while the structure is in operation and in the event of a possible abandonment of all or part of it.

The extent of marine growth on the structures depends on their surface, light and current conditions, and the depth of the structure.

A concrete installation in depths down to more than 300 metres in the North Sea forms a local habitat for species normally found either in the shore zone or only at greater depths.

Research shows that growth over a larger and more varied surface area occurs more rapidly on a steel platform jacket than on a concrete structure, but that this difference declines over time. In addition to depth, light and current conditions represent important parameters in determining growth speed and species diversity. Because of the many different angles and surfaces provided, species diversity is greater on a jacket than on a concrete structure, but the latter may be more favourable for benthic sessile organisms. This is because the vertical orientation protects these species from sedimentation. Over time, they will attract mobile fauna such as fish and crustaceans.

Studies of biomass production on platform jackets shows that this is much higher than in coastal kelp forests, which are among the most productive natural environments in Norway. No similar studies have been conducted for concrete installations. Even through growth on jackets and on concrete structures cannot be directly compared, the latter unquestionably contribute much new habitat to the North Sea.

Concrete structures in the Norwegian North Sea sector, which largely comprises a hard seabed, are installed in depths from 82m (Sleipner A) to more than 300m (Troll A). They accordingly contribute local habitats for a number of hard substrate species.

Possible removal of a concrete installation would eliminate the fauna established on this structure, and natural conditions would eventually return to those which prevailed before it was installed. That would reduce both species diversity and the quantity of biomass compared with the present position.

Research shows that abandoning concrete installations would have no effect on fish at the population level but that, because of the increase in biomass and species diversity, these structures could function as a zone of greater density compared with areas further away.

When in operation, oil installations have a negative effect on fisheries because of safety zones and restrictions on movement. Ignoring their size, however, the effect of abandoned concrete installations would not differ from other objects (rocks and wrecks, for example) on the seabed which must be avoided. Providing that all other foreign objects on the seabed are removed, trawlers will be able fish right up to an abandoned concrete installation. In theory, area loss would be confined to the exterior boundary around all the shafts and tanks on the seabed, and all parts of this external edge should be trawlable. So abandoning concrete installations would have little impact on trawlers fishing in the immediate area.

Abandoning concrete installations is also expected to have little negative effect on seine fishing in the North Sea. Target species for this fishery move freely, and fishing takes place wherever the species are available in harvestable quantities at any given time. The probability that any shoal which a seiner is seeking to catch will swim into one of the 12 concrete installations is regarded as very low.

The database of shipping accidents maintained by the Norwegian Maritime Directorate (NMD) shows no increased frequency of episodes close to oil installations. Registered episodes are related to vessels directly associated with the field. However, intensive monitoring of the waters around the installations is thought to have reduced the number of accidents, and such surveillance would probably be reduced with the decommissioning of the installation.

Of the concrete installations, only the Ekofisk tank and Sleipner A lie in sea areas where a future traffic picture could create conflicts between vessels. If a danger of collisions between ships exists in these waters, a threat of vessels colliding with abandoned concrete installations must also be presumed to exist.

The disadvantage of abandoning concrete installations has been assessed in connection with the decommissioning of the Frigg field. Leaving such structures in place without cutting them down would have a moderately negative impact on free movement for shipping. To ensure such freedom of movement, it has been calculated that an installation must be cut down to 55 metres beneath the sea surface.

The Ministry of Petroleum and Energy has earlier estimated the risk of collision between ships and an abandoned concrete installation as small compared with the risks of removal, providing navigational aids (including lights and electronic signposting) are placed on the installation.

1.2 Disposal on land

This report assumes that the platform topsides and all possible waste hazardous to health and the environment have been removed in conformity with the regulations before the installation is taken to land.

This means that, on arrival at the receiving facility, the structure will consist only of reinforced concrete polluted to varying degrees with various substances hazardous to health and the environment, marine growth and equipment required for the tow to land.

The main activities, which should be conducted in the following order, affecting emissions/discharges will therefore be

1. environmental reconstruction – removal of all waste hazardous to health and the environment
2. removal and treatment of marine growth
3. demolition (chopping/blasting/breaking up) of the actual concrete structure.

Achieving an environmentally acceptable execution of the above-listed processes will call for substantial amounts of space.

Most of the environmental reconstruction will relate to various types of treatment likely to yield large volumes of polluted washwater and high consumption of different chemicals. Such reconstruction must accordingly be pursued in a separate area, with strict standards for collecting process water and secure intermediate storage for various types of hazardous waste, marine growth and lightly polluted sections (demolished concrete).

However, the largest area is expected to be required for intermediate storage of crushed concrete and rebars. It will be important to have sufficient space for separating clean and contaminated concrete.

Clean concrete can be recycled for such purposes as infill, erosion protection or aggregate in new concrete, while polluted material must be delivered to an approved reception plant. Much of the concrete which has been in contact with oil or other chemicals (from the storage cells, for example) is expected to be polluted and difficult to clean.

Research shows that recycling concrete is environmentally beneficial, in part by reducing the use of non-renewable natural resources. However, such recycling requires more energy than producing new concrete.

Rebars can also be recycled. In addition to being environmentally favourable, this could also be a source of revenue. Energy consumption is higher than for producing new rebars.

In addition to challenges related to curbing the discharge of environmental toxins to water, the concrete demolition process would present challenges in preventing the spread of dust. The work is also expected to generate a great deal of noise.

1.3 Energy and environmental account

Disposal solutions and associated environmental assessments will often be qualitative in nature and involve some degree of subjective opinion. It is accordingly useful to assess quantitative methods, such as energy consumption and emissions to the air with various operations or solutions.

An energy and environmental account has been prepared for this report covering energy consumption with associated CO_2, NO_x and SO_x emissions for offshore abandonment and disposal on land respectively.

It should be noted that a multitude of different proposals exist for the various sub-operations and the way concrete installations should be removed to land.

For removal to land, however, the installation must first be refloated, then towed to land and brought ashore as modules/sections of varying size before being broken up. Residues must then be sorted and disposed of either through recycling or by delivery to an approved landfill.

Based on data from various sources, disposal of the Frigg TCP2 installation would consume 673 000 gigajoules and emit 55 000 tonnes of CO_2, 750 tonnes of NO_x and 205 tonnes of SO_2.

1.4 Conclusion

The environmental impact of abandoning concrete installations in the North Sea is limited. The biological production which currently occurs on these installations would disappear if they were removed, and the structures do not affect fish populations or fishing.

If the installations are fitted with lights and navigation equipment, the threat of any conflict with shipping is small. Were the installations also cut down to 55 metres beneath sea level, they would present no restrictions to shipping at all.

At the same time, the potential environmental impact of removal to land is substantial. A danger of accidents naturally exists when refloating installations and moving them to land, but the conflicts primarily relate to environmentally acceptable environmental reconstruction, demolition and intermediate waste storage. These operations are expected to involve a high risk of dispersing polluted water as well as much dust and noise.

A large amount of space would be required, both on land and in the sea, and the level of potential conflicts with neighbours is expected to be high.

In terms of energy consumption and emissions to the air, abandonment of a concrete structure at sea would be far more favourable than disposing of it on land.

From an overall perspective, therefore, offshore abandonment would clearly have the lowest environmental impact.

2. Introduction

The Norwegian Petroleum Directorate (NPD) invited the Norwegian Climate and Pollution Agency (Klif) and the Petroleum Safety Authority Norway (PSA) in October 2010 to participate in a joint project to study key issues related to the final disposal of concrete installations on the Norwegian continental shelf (NCS). The project aims in part to look at the environmental impact of the various disposal solutions for these structures. Multiconsult has been commissioned by Klif to prepare a sub-report in this issue.

The present report considers the various environmental impacts of abandoning these structures offshore or removing them to land for final disposal. It also presents possible alternatives for demolition and opportunities for recycling.

This report falls into two parts. Chapter 3 presents an assessment of the environmental impact of abandoning concrete installations offshore, while chapter 4 assesses the impact of removal to land.

Chapter 5 presents an overall assessment of the various environmental consequences.

The report deals with the following aspects:

- artificial reefs
- conflicts with fishing
- conflicts with shipping
- noise, dust, emissions to the air and discharges to water
- area requirements
- disposal and recycling of materials
- alternative applications on land
- energy and environmental account compared with offshore abandonment

2.1 List of abbreviations

Arpa and AIS systems	Radar detection of other vessels or objects
CB	Cargo barge
Ecdis	Electronic chart display and information system
GBS	Gravity base structure (concrete)
IMO	International Maritime Organisation
MSV	Multi service vessel
NCS	Norwegian continental shelf
Nilu	Norwegian Institute for Air Research
Ospar	Oslo-Paris convention for the protection of the marine environment of the north-east Atlantic
Safetec	Provider of integrated risk and asset management services
Slop	Oil drilling waste
SSCV	Semisubmersible crane vessel
SV	Supply vessel
TCP2	A concrete installation on the Frigg field
TOC	Total organic carbon
Woad	Worldwide Offshore Accident Databank

3. Abandoning concrete installations offshore

The question of whether oil or gas installations should be abandoned or removed to land is regulated by chapter 5 [i] of the Norwegian Petroleum Activities Act and Ospar decision 98/3 [ii]. Chapter 5 of the Act requires the licensee to produce a decommissioning plan which specifies how a facility will continue to be used for petroleum activities or removed wholly or in part.

The main rule in Ospar decision 98/3 is removal. Exceptions can nevertheless be made if an overall assessment shows significant reasons for not removing an installation to land. Such reasons include opportunities for reuse, environmental effects and the impact on other uses of the area.

An assessment of whether to abandon or remove to land must also take account of such documents as IMO resolution A 672 (16), which provides guidance on which types of installations are to be removed but also opens for leaving structures in place if removal to land involves large costs, danger to life or health, or a risk of harming the marine environment.

Abandonment is assessed as an alternative to removal and breaking up in a number of countries. The following chapters provide an overall evaluation of the possible effects of abandonment on marine life in the form of artificial reefs, and on fishing and shipping.

These assessments are based on published scientific work and on publicly available reports.

Abandonment will cut decommissioning costs, while significantly reducing disruption to the seabed and to sediments with associated environmental impacts [iii].

In the event of abandonment, the structure is expected to stand for several centuries before being eroded away by wind and weather. Debates on the aging of concrete installations and the effect of different environmental factors are discussed in a 2009 report from the PSA [iv].

3.1 Influence of artificial reefs on marine life

Bottom conditions in the Norwegian North Sea vary from fairly coarse, hard and stony surfaces to finer clayey sediments. Water depths are 100m in central southern areas, 100-150m in central areas and from 150m to almost 300m in the north. To the east, they descend towards 700m in the Norwegian Trench.

Every artificial structure, including oil and gas installations, which sticks up from the seabed will function as an artificial reef.

Challenges relate first and foremost to marine growth and the effect on fish.

3.1.1 Marine growth

Marine growth on structures depends on the surface involved, light and current conditions, and the depth in which the structures stand.

An installation positioned in depths down to more than 300 metres in the North Sea forms both a local habitat for species normally found in the shore zone, close to shore or only at greater depths such as deepwater stone coral (*Lophelia pertusa*). Around the North Sea, some Norwegian fjords are the only areas which can show similar depth gradients in one location.

The time it takes for a structure on the seabed to be covered with marine organisms depends on ambient physical conditions, the supply of free-swimming marine larvae which can attach to the structure, and the suitability of the structure’s surface for the attachment of such larvae. Organisms on the structure will eventually comprise both sessile organisms and mobile species which move freely.

Figure 1 shows the progress of marine growth on a steel cylinder installed in the German North Sea. It stood in 28m of water and is representative for this depth and area. The figure nevertheless provides a good illustration of how sessile and mobile species respectively become established in an early phase [v].

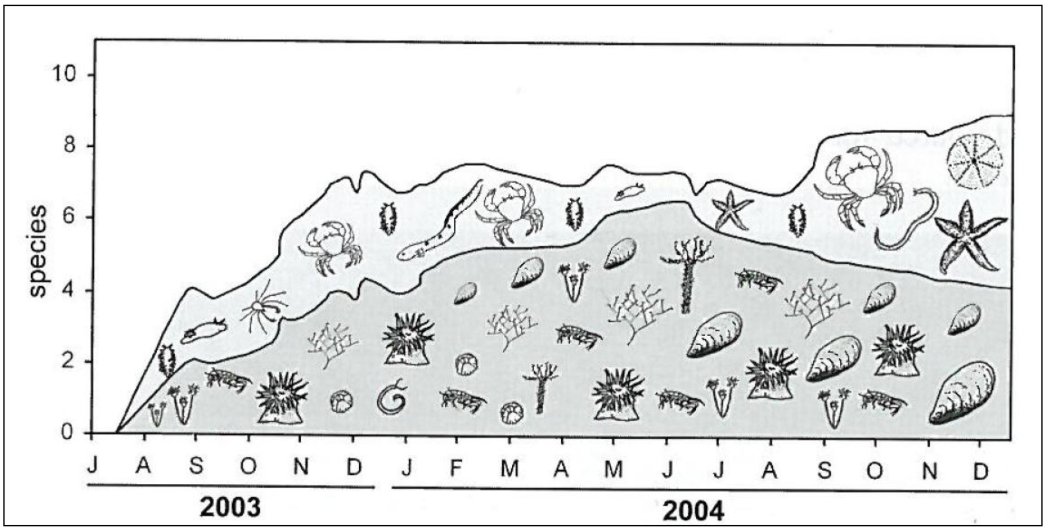

Figure 1. Development of an animal community on a steel cylinder. The illustration distinguishes between anchored (dark grey background) and mobile (light grey background) species on the structure. (Source:[vi]).

Studies of marine growth are available for both concrete installations and platform jackets (support structures comprising a steel framework).

Jackets offer a large surface area compared with concrete installations. *Guerin* [vii] refers to work where the surface of a jacket in a depth of 45m provides a growth area of 12-16 000sq.m. Assuming that the mean diameter of a GBS shaft is 10m and that there are three of these, a structure of this type at a corresponding depth will have a surface area of 5 000sq.m.

Jackets also provide greater dynamism in terms of wave and current exposure, since a number of areas on such a structure will lie at any time on the “front” and “back” sides compared with a concrete installation. This is also reflected in Figure 2, and is documented by *Guerin*, who finds that the jacket’s variable structure and surface orientation to light, waves and current will produce a rich fauna and flora [vii].

In addition to physical conditions at the location, the type of surface will help to determine which species take hold. That applies particularly in the first phase when free-swimming larvae attach themselves.

As figure 3 shows, the degree of coverage of various organisms differs between the exterior and interior sides of a jacket. The biggest difference is seen in the uppermost 15m, where the macroalgae dominate on the exterior face. It also emerges clearly that their overall dominance is greatest on those parts of the structure which are subject to the biggest wave influence. Macroalgae exploit sunlight and make a significant contribution to primary production in the platform ecosystem. The remaining surface-covering species are particle consumers (filter/suspension feeders).

Guerin [vii] refers to studies which show biomass production of close to 155kg/sq.m on jackets. By comparison, biomass in the kelp forests along the Norwegian coast, one of the richest and most productive natural environments known in Norway, is 30kg/sq.m [viii]. This shows that production of organic material on a platform jacket can far exceed the “natural” output of biomass.

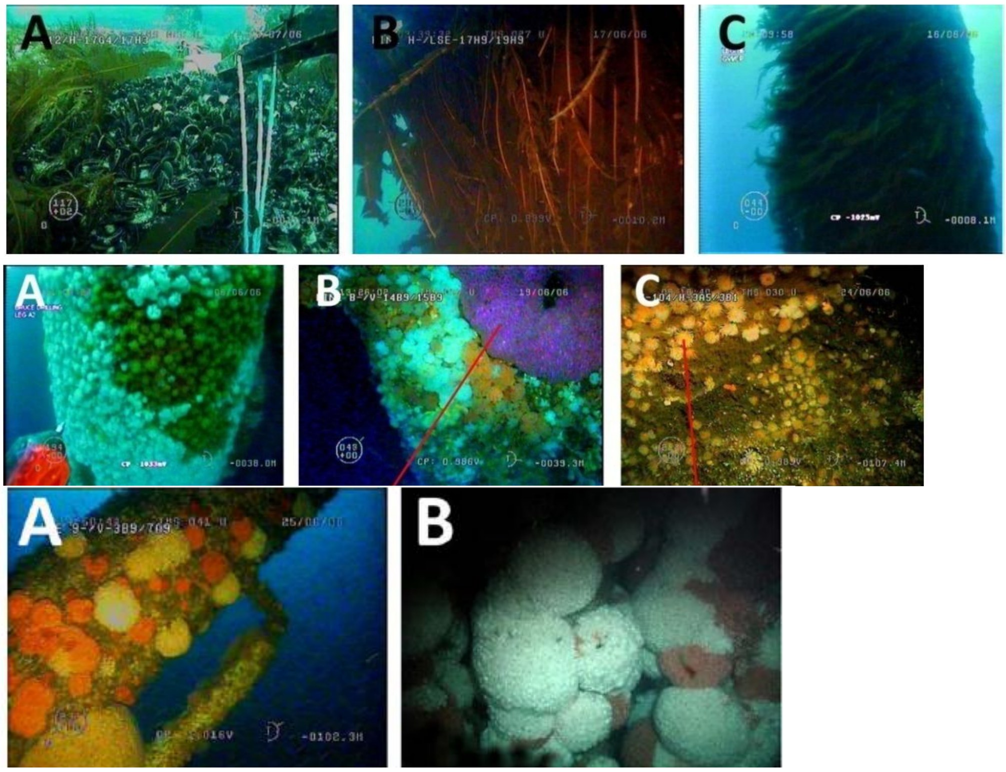

Figure 2. Example of marine growth on a platform jacket (from [vii]).

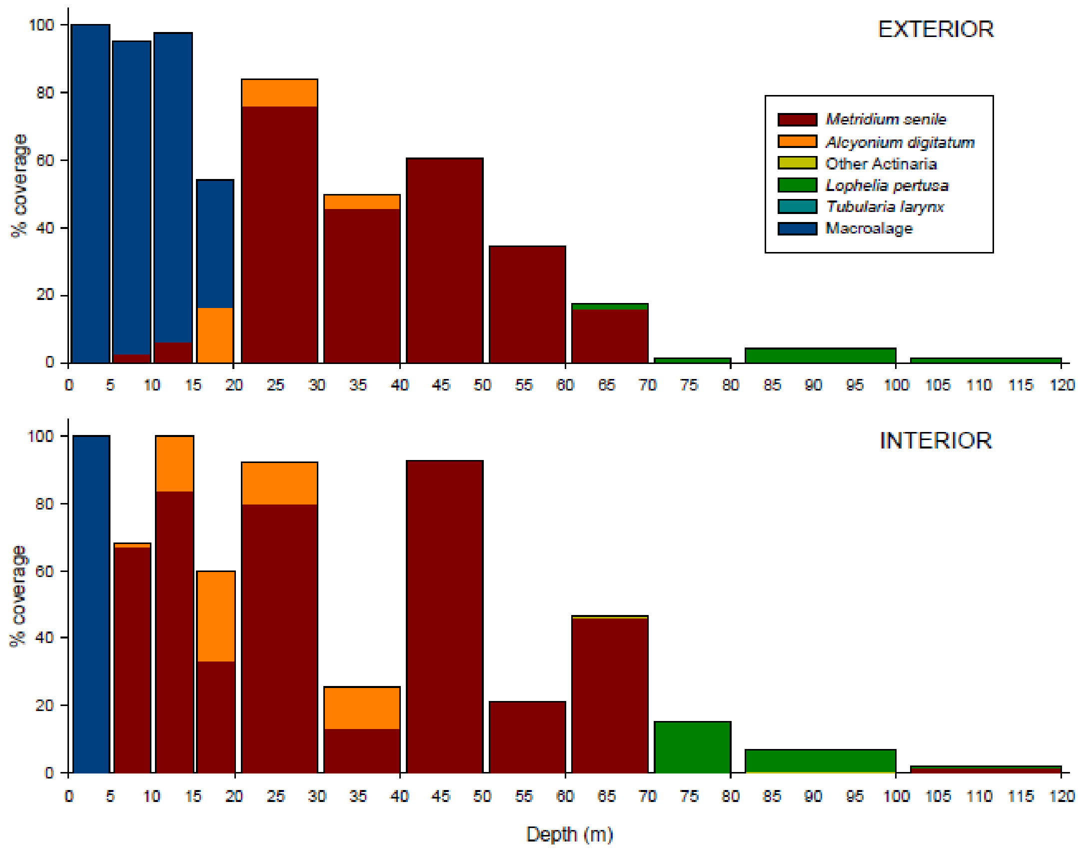

Figure 3. Coverage of dominant anchored organisms on the exterior (exposed) and interior (less exposed) faces of a platform jacket in the North Sea. (Source: [vii]).

Sessile organisms are dependent on a suitable location to survive. Light and current conditions are important parameters in determining the survival basis for such species. Once attached, they have little opportunity to move. Structures such as concrete installations are favourable for sessile organisms, since the vertical orientation minimises sedimentation. Such species will attract mobile fauna like fish and crustaceans.

Mathias H Andersson et al [ix] have studied differences in marine growth on steel and concrete through field experiments on the Swedish west coast. Run for 12 months, this study showed big variations. It must be emphasised that the experiment covered only a single season. In 2005, *Craig J Brown* [x] studied colonisation on concrete with other substrates, including steel. The substrates were examined after three, six, nine and 12 months. The results showed big variations in marine growth between the different materials, but these reduced over time. This indicates that differential growth on jackets and concrete installations declines with time.

While growth on jackets and concrete structures cannot be compared directly, the latter unquestionably provide new habitats in the North Sea. In the Norwegian sector, where the seabed is mainly hard, concrete structures are installed in depths from 82m (Sleipner A) to more than 300m (Troll A). They accordingly provide local habitats for a number of hard-seabed species.

Concrete structures have been used as artificial reefs for more than 40 years, and have expected lifespans of over three centuries [xi]. Concrete installations in the North Sea already act as such reefs and can continue to do so if they are abandoned *in situ*.

Possible removal would eliminate the fauna established on the structures, and natural conditions would eventually return to those which prevailed before the development.

3.1.2 Fish

Grossman et al [xii] reviewed a number of scientific studies in 1997 to see if it was possible to conclude that establishing artificial reefs yielded a regional increase in fish stocks. This review gave no indication of a production rise at the population level, but documented that a lot of the fish congregated on the artificial reef. According to *Grossmann et al*, this is because access to hard seabed habitats is not a factor which limits the size of fish populations.

More recent studies from the North Sea show similar results. *Løkkeborg et al*, for instance, showed in 2002 that the volume of commercially exploitable specifies such as cod and saithe in the immediate vicinity of installations varies both during the year and by distance from the structure [xiii]. *Soldal et al* reported in the same year that both composition and volume of fish species varied in time and space close to an installation [xiv].

Based on the research material cited above, it can be concluded that abandonment of concrete installations will have no effect on fish stocks at the population level, but that these structures could serve as a zone of greater density compared with areas further away.

3.1.3 Summation of artificial reefs

Concrete installations are favourable for the growth of attached organisms. Over time, these will attract mobile organisms such as fish and crustaceans. Possible removal of a concrete installation would eliminate the fauna established on this structure, and natural conditions would eventually return to those which prevailed before it was installed. That would reduce both species diversity and the quantity of biomass compared with the present position.

Research shows that abandoning concrete installations would have no effect on fish at the population level but that, because of the increase in biomass and species diversity, these structures could function as a zone of greater density compared with areas further away.

3.2 Conflicts with fishing

Fishing is not permitted in the safety zones currently established around oil and gas installations. These zones could be reopened with the removal of the installations.

All Norwegian fishing vessels above 15m automatically report their position at regular intervals to the Directorate of Fisheries' tracking centre. This means that the speed of a vessel can be estimated from the distance and time between reported positions. Knowing which group of vessels it belongs to, the tracking centre can thereby assess whether a fishing boat is engaged in active fishing. Via the fisheries directorate, Multiconsult has obtained position data for Norwegian fishing craft in 2009.

By assembling scientific articles, Multiconsult has also assessed potential conflicts between abandoned concrete installations and fishing. Assessments of fish volumes around the structures are detailed in chapter 3.1.2.

3.2.1 Fishing areas

The Norwegian North Sea can be divided into four areas on the basis of distinctive ecological profiles [xv]. The most important fisheries for adult cod, saithe and haddock as well as for species such as Norway pout, herring and mackerel are found in the north, in depths from 100-200 m. Growth areas for blue whiting and habitats for deepwater species such as greater argentine and roundnose grenadier are found in the Norwegian Trench. The central area is home to species such as haddock, whiting, young herring and brisling. Production is lower than in the northern areas. The eastern sections function as growth areas for herring and cod.

3.2.2 Trawling

As figure shows, trawling was carried on during 2009 in the area around Oseberg, Troll, Gullfaks and Statfjord. These waters are attractive for trawlers because of the combination of available fish resources and favourable bottom conditions for trawling.

The trawl is normally deployed in a specific position and then towed in a given direction. The trawler can change course throughout the operation, but lacks the manoeuvrability available when the trawl is not out (see figure 4). This means that the vessel needs a larger area to turn or change course. Modern trawlers can install instruments on the trawl which tell them where the latter is on the seabed relative to the ship at all times. The navigator can thereby avoid objects (such as rocks or wrecks) on the seabed which might damage the gear. As when changing course, manoeuvring is somewhat reduced but this is taken into account.

Apart from their size, abandoned concrete installations will be no different from other objects to be avoided on the seabed.

Providing that all other foreign objects on the seabed are removed, trawlers will be able fish right up to an abandoned concrete installation. In theory, area loss would be confined to the exterior boundary around all the shafts and tanks on the seabed, and all parts of this external edge should be trawlable.

So abandoning concrete installations would have little impact on trawlers fishing in the immediate area.

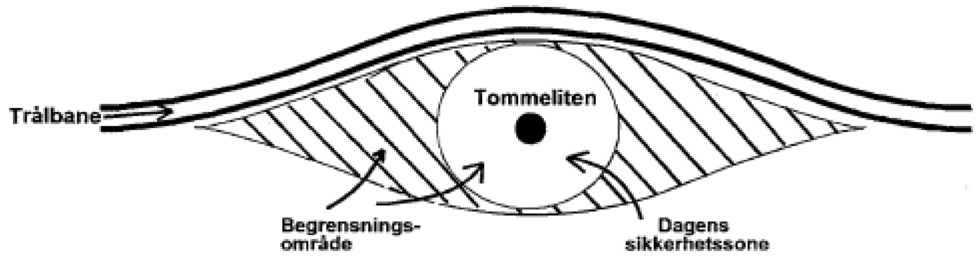

Figure 4. How a trawler avoids an installation. The illustration shows Tommeliten, with a 500m safety zone (Source: [xvi]) [text: Trawl path, Restricted area, Existing safety zone]

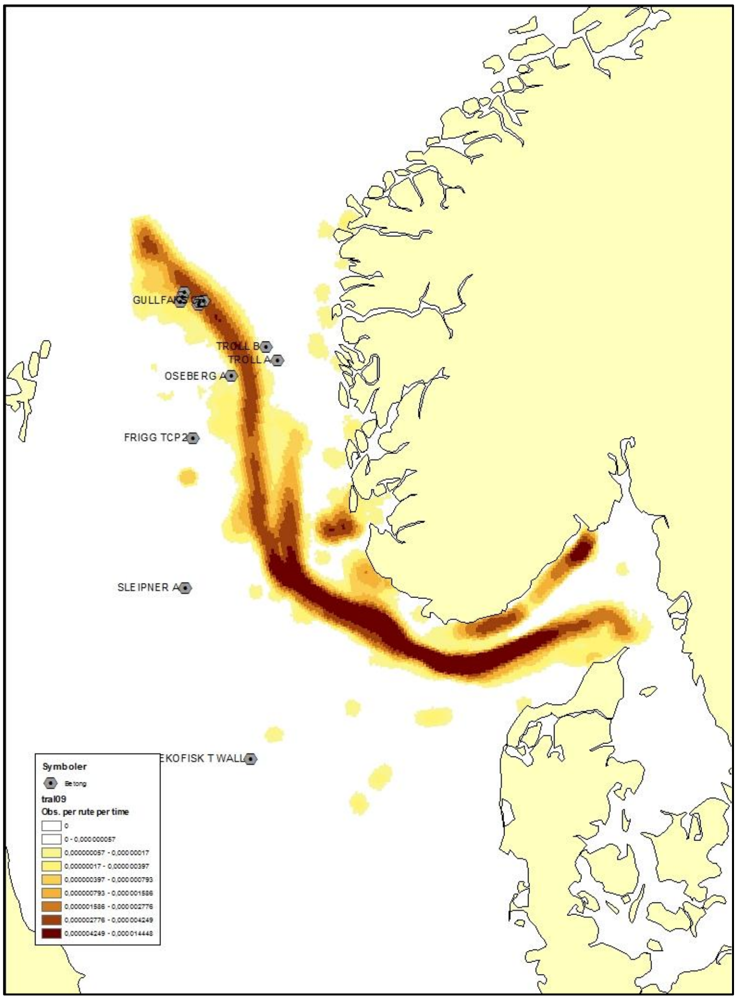

Figure 5. Overview of Norwegian trawlers actively fishing in the North Sea during 2009. One pixel in the colour shading represents 6 x 6 kilometres. [text: Symbols Concrete Trawl 09 Observed per course per hour]

3.2.3 Seine fishing

Figure 6 shows areas where seine fishing was carried on in the North Sea during 2009. Seining relates to pelagic fish resources such as herring, mackerel, horse mackerel and to some extent sprat (brisling). Catch areas vary during and between years, depending on where the fish are located.

Seining is not as dependent as trawling on favourable bottom conditions, since its efficiency depends on the fish congregating in tight shoals. A seiner will normally locate a shoal with sonar, and then position itself in relation to the shoal's movements. Were a shoal to swim towards an abandoned concrete installation, the latter could be an obstacle to fishing.

The Norwegian North Sea has a total of 12 concrete installations. The probability that any shoal which a seiner is seeking to catch will swim into one of these is regarded as small.

Abandoning concrete installations in Norway's North Sea sector is accordingly expected to have little negative effect on seine fishing in these waters.

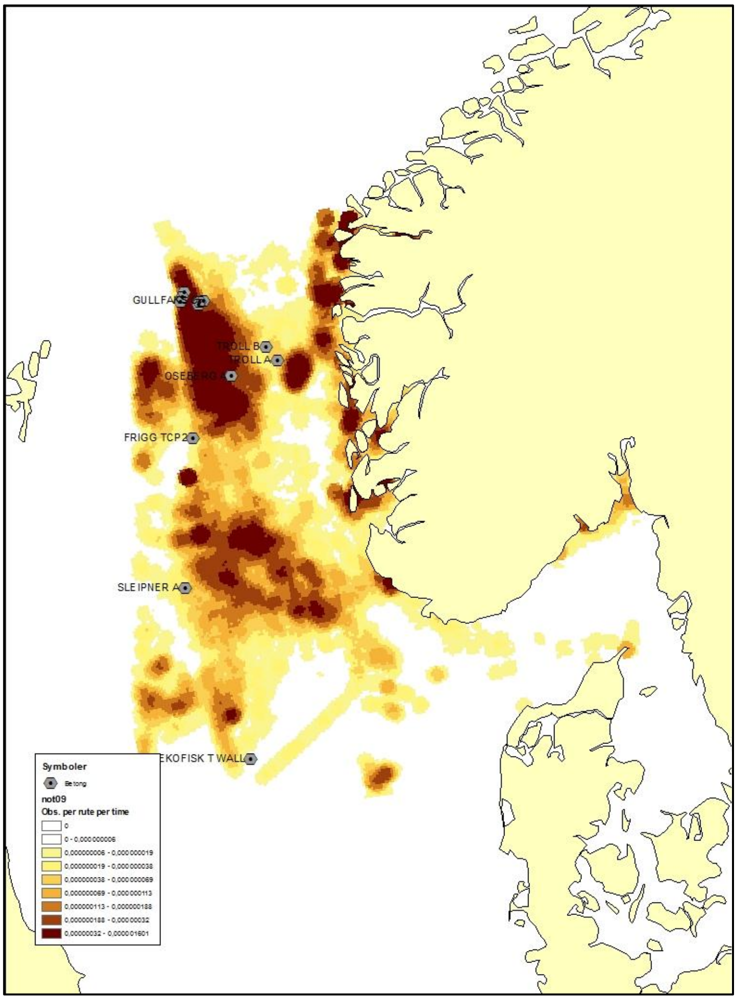

Figure 6. Overview of Norwegian seiners actively fishing in the North Sea during 2009. One pixel in the colour shading represents 6 x 6 kilometres. [text: see figure 5]

3.2.4 Summation of conflicts with fishing

In operation, oil installations have a negative effect on fisheries because of safety zones and restrictions on movement. Ignoring their size, however, the effect of abandoned concrete installations would not differ from other objects (rocks and wrecks, for example) on the seabed which must be avoided.

Providing that all other foreign objects on the seabed are removed, trawlers will be able fish right up to an abandoned concrete installation. In theory, area loss would be confined to the exterior boundary around all the shafts and tanks on the seabed, and all parts of this external edge should be trawlable. So abandoning concrete installations would have little impact on trawlers fishing in the immediate area.

Abandoning concrete installations is also expected to have little negative effect on seine fishing in the North Sea. Target species for this fishery move freely, and fishing takes place wherever the species are available in harvestable quantities at any given time. The probability that any shoal which a seiner is seeking to catch will swim into one of the 12 concrete installations is regarded as very low.

3.3 Conflicts with shipping

Intensive monitoring of ship traffic has been established around North Sea oil and gas installations and the waters immediately surrounding them. This surveillance is intended to provide an early warning to vessels on a collision course with installations in order to protect the structures, their personnel and the environment against possible oil spills from a collision. When concrete installations are abandoned, a correspondingly specific monitoring of these structures and the surrounding waters cannot be expected. On the other hand, an abandoned installation will not represented a greater hazard then other fixed objects in the shipping lane.

3.3.1 Traffic pattern

Maritime traffic has increased worldwide over the past 20 years (Ospar [xvii]), and that also applies to the North Sea. Shipping movements in the Norwegian sector are small compared with traffic further south, and total about a quarter of the total distance sailed for the whole North Sea [xviii]. The main pattern in the traffic picture is shown in figure 7.

As the figure shows, traffic is greatest down towards the English Channel, but a relatively large amount crosses the North Sea. In addition to crossing traffic, the figure shows considerable movements to and from the Ekofisk area.

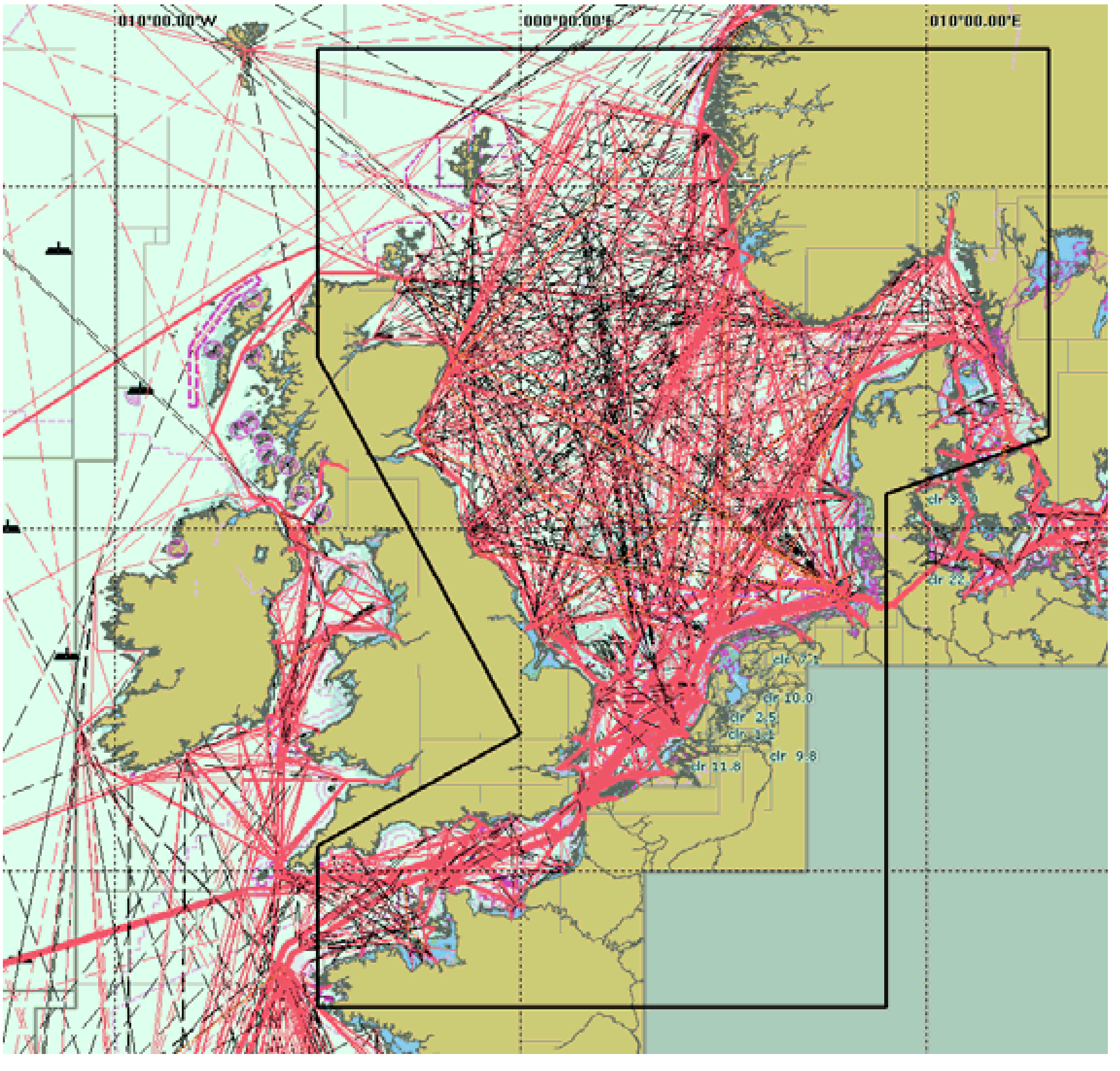

Figure 7. Individual vessel movements in the North Sea. The thickness of the lines shows the most active shipping lanes, but gives no indication of the number of vessels. [xix]

In connection with updating a regional impact assessment for the North Sea, Safetec has prepared a description of maritime traffic in the North Sea (see figure 8)[xx]. Some 10-19 000 vessels pass through the main shipping lane. Traffic crossing the North Sea outside the main lane varies between 150 and 1 000 sailings per year.

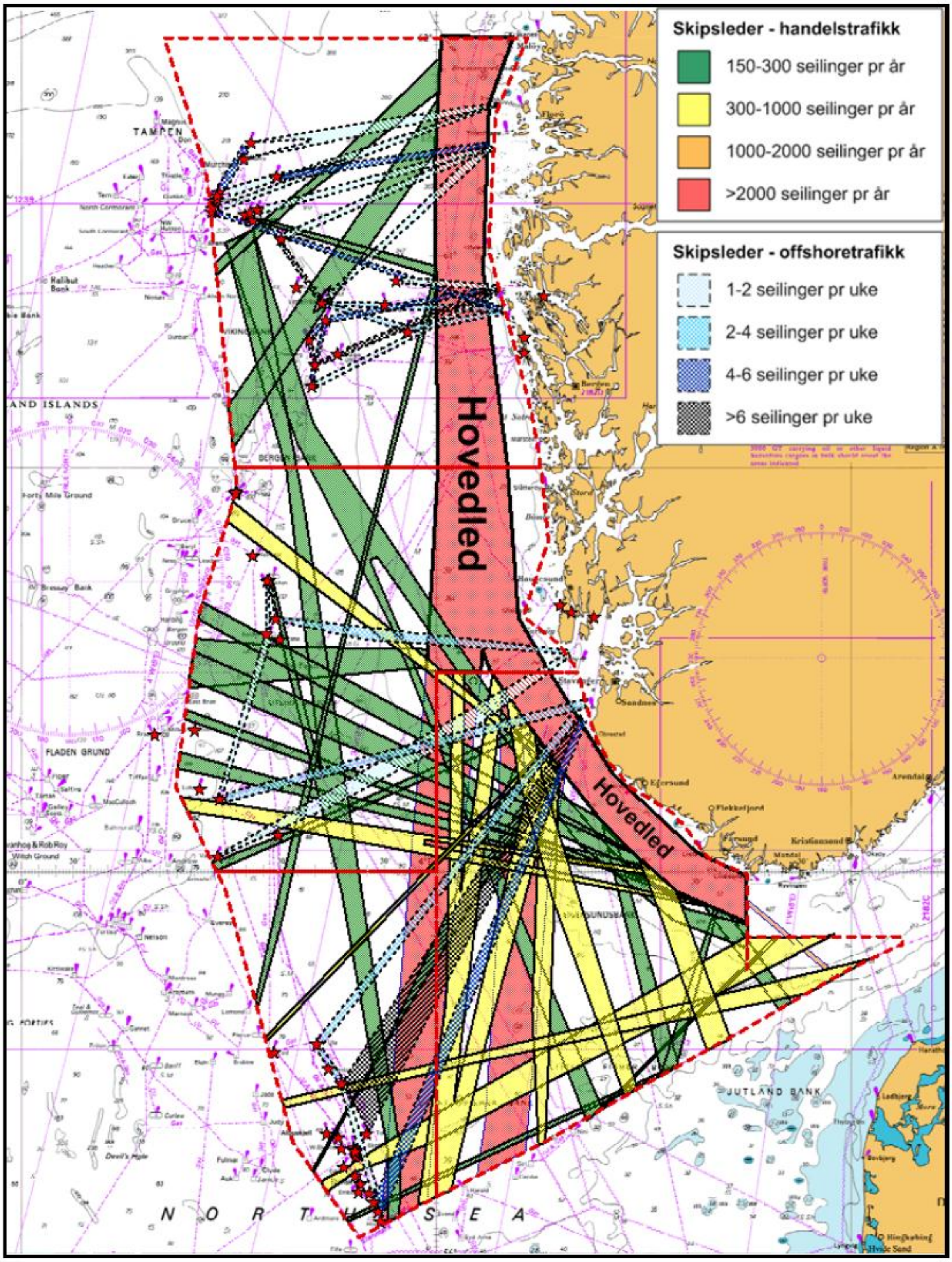

Figure 8. Maritime traffic in the Norwegian North Sea (Source:[xx]). [text: Main lane Shipping lanes – merchant shipping sailings per year Shipping lanes – offshore traffic sailings per week]

3.3.2 Collisions

Woad has registered 465 cases between 1970 and 2002 where ships have collided with oil or gas installations. Thirty per cent of these incidents in 1980-2002 involved vessels with no connection to the fields. The figures do not include accidents related to the installation or repair of structures. Vessels related to the installations accounted for 95 per cent of all incidents in 1990-2005 in the UK North Sea sector [xxi].

A combination of historical vessel accidents and the traffic picture in the North Sea is shown in figure 9. Thirty per cent of the registered accidents relate to fishing vessels. The figure shows no increase in accident frequency involving ships close to oil and gas installations, over and above vessels directly related to the field [xxii].

The NMD administers a database which includes records of vessel accidents and near misses which have resulted in material damage or personal injury [xxii]. According to the Norwegian Coastal Administration, the registration of position in the database is of varying character[1]. In addition to position, the accidents are linked to the waters and type of seaway in which the accident occurred. This means that incidents directly related to oil fields can be separated from those related to ordinary maritime activities outside these fields. The incidents are also recorded by the relevant type of accident and the vessel categories involved. This makes it possible to isolate collisions for other incidents and to distinguish between vessels directly related to the installations and other “accidental” vessels. Information in the database dates back to 1981.

The NMD’s database shows that the vessels involved in all registered collisions with oil and gas installations were directly connected with petroleum activities.

[1] Personal report from Åmot, Norwegian Coastal Administration.

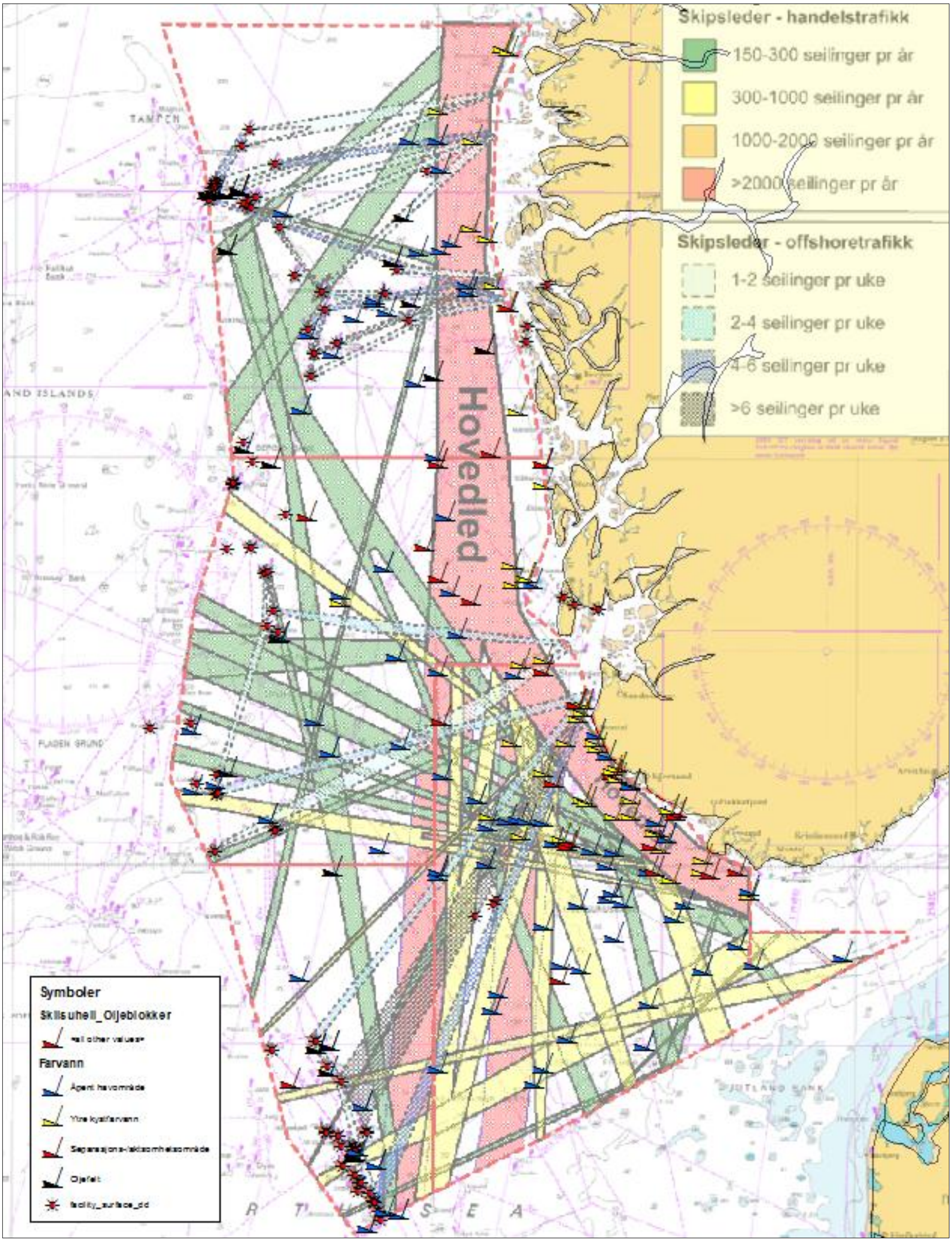

Figure 9. Vessel accidents 1981-2009 combined with the traffic analysis and the location of surface objects related to the oil and gas industry (Source:[xxii].) [text: **Symbols** Ship accidents – oil blocks All other values **Sea area** Open waters Outer coastal waters Segregation/area of special caution Oil field]

3.3.3 Collision risk

On the basis of the traffic pattern and the number of vessels, Safetec has identified existing and future areas where conflicts between ships could arise (see figure 9). Figure 9 shows that the potential for conflict is highest in the main shipping lane and lower around oil installations. Of concrete installations, only the Ekofisk tank and Sleipner A lie in sea areas with a traffic picture where conflicts with ships might occur. Should a risk of collision between ships exist in these areas, it must also be assumed that a risk exists for ships colliding with abandoned concrete installations

In a study of year-round petroleum activity in the Lofoten-Barents Sea area [xxiii], Det Norske Veritas (DNV) has estimated a general collision risk of 0.00000057 incidents per nautical mile sailed.

The PSA's risk assessment for 2010 [xxiv] includes the number of ships on a collision course with installations over time (see figure 10). The reduction in the number of incidents relates to improved surveillance.

Figure 10. *Incidents involving ships on a collision course with NCS installations (Source:[xxiv].* [text: Incidents per 1 000 surveillance days]

In an MSc thesis at the University of Stavanger, *Skarestad* has analysed the risk of a collision between an oil and gas installation and a vessel not connected with the installation [xxv]. This work refers to Safetec's Collide II collision model, where the annual collision frequency between vessel and installation depends on the following factors:

- annual number of vessels in the area around the installation
- probability of a vessel being on a collision course
- probability that a vessel is unable to take avoiding action.

The probability that a ship is on a collision course depends on whether the navigator knows of the installation, how the vessel's course is planned and whether the installation lies between the ship and its destination.

Skarestad concludes that the probability that knowledge of an installation exists rises with the time it has been on the field.

The disadvantages of abandoning concrete installations were assessed in connection with the decommissioning of Frigg. If the concrete installation is cut down to 55m beneath the sea surface, the consequences for maritime traffic are considered to be moderately positive. The positive factor relates to free movement compared with the position before field decommissioning. Leaving the concrete structure without cutting it down would have a moderately negative impact on free movement for shipping [xxvi].

Abandoning concrete installations is also supported in Report no 38 (2003-2004) to the Storting and in Proposition no 9 (2008-2009) to the Storting, where the Ministry of Petroleum and Energy regards the consequences as minor compared with the risks of removal – providing navigational aids are attached to the installation. The ministry also requires that the position be updated in electronic charts and navigational databases.

Collisions between field-unrelated vessels and active oil installations are largely avoided by active traffic monitoring. A corresponding level of surveillance cannot be expected after concrete installations have been abandoned. The position can accordingly be compared with the general collision risk which exists between vessels at sea. The risk of collision between vessels and abandoned concrete installations will be lower than between two vessels. This is because a fault causing a collision can only arise with the ship in the case of a vessel and an installation, while it could occur with either or both of the vessels in the other case.

3.3.4 Risk reduction

A standard exists for the technical aids for collision avoidance which must be carried by vessels related to the petroleum industry [xxvii]. Defined as collision barriers, these are largely based on radar detection of other vessels or objects (Arpa and AIS systems).

The decline in episodes of vessels on a collision course with installations (figure 9) probably reflects improved monitoring. That also accords with DNV’s conclusion in the impact assessment for petroleum operations in Lofoten-Barents Sea, where traffic monitoring is considered to have a good effect in reducing the collision risk [xxviii].

Groundings often relate to navigational errors, and can be regarded as analogous to a collision between a vessel and an abandoned concrete installation. Use of electronic charts with Ecdis achieves a reduction in the order of 15-20 per cent in the risk of grounding.

In the absence of traffic monitoring, adequate marking of abandoned installations and warnings via Ecdis and other navigational databases will accordingly reduce the threat of collision significantly. Vessel navigators will then see the installations on their electronic charts when planning a course, and be visually alerted when the structure is sufficiently close. Furthermore, the transmission of AIS signals from the installation will alert the navigator to a possible risk of collision via the vessel’s systems.

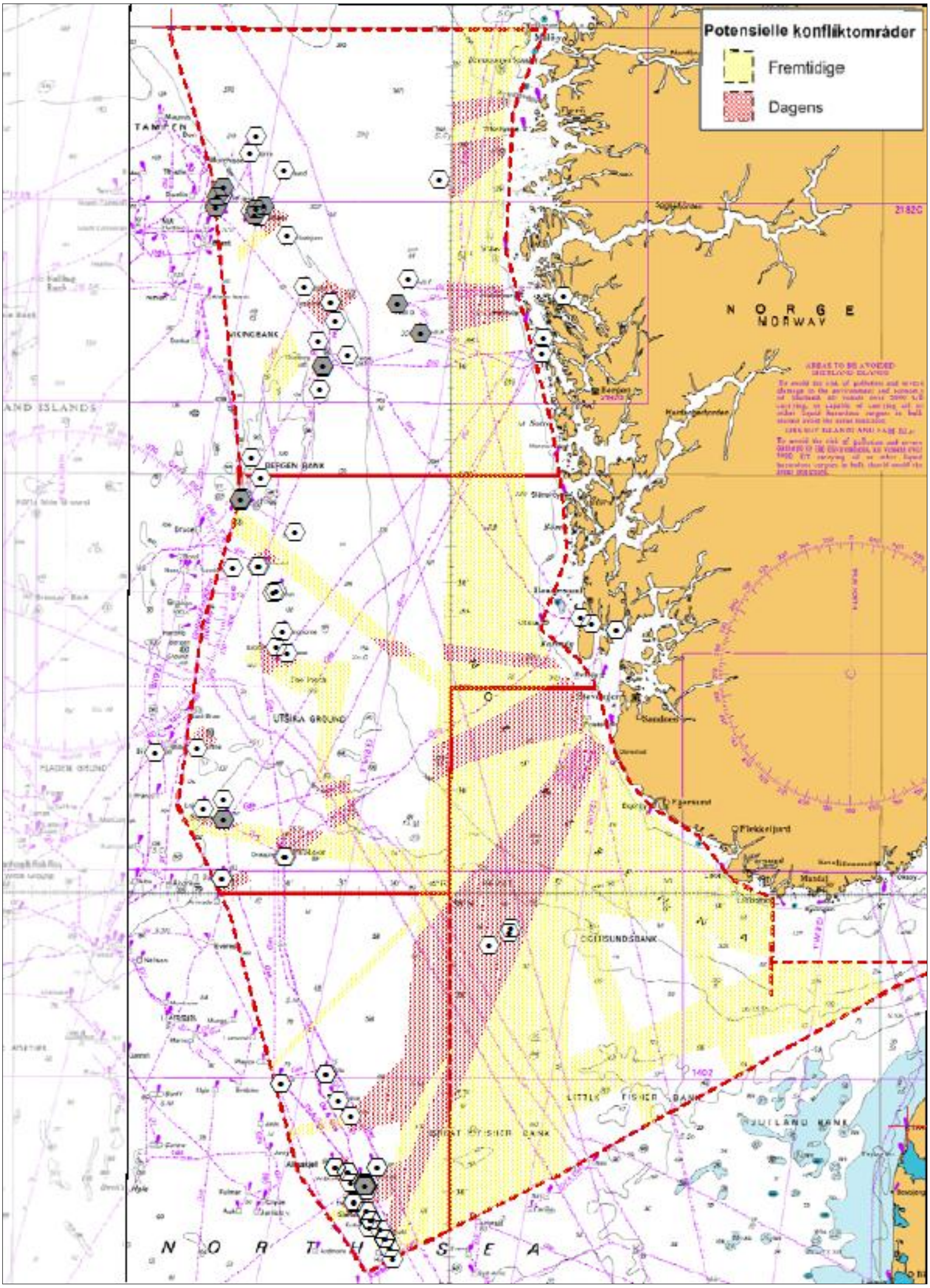

Figure 4. Present and future potential conflict areas for shipping in the North Sea. Concrete installations are indicated by solid symbols (Source:[xxiv]) [text: Potential conflict areas Future Present]

3.3.5 Summation of conflicts with shipping

The database of shipping accidents maintained by the NMD shows no increase in the frequency of episodes close to oil installations. The registered episodes are related to vessels directly associated with the oil field. However, intensive monitoring of the waters around the installations is thought to have reduced the number of accidents, and such surveillance would probably be reduced with the decommissioning of the installation.

Of the concrete installations, only the Ekofisk tank and Sleipner A lie in sea areas where a future traffic picture could create conflicts between vessels. If a danger of collisions between ships exists in these waters, a threat of vessels colliding with abandoned concrete installations must also be assumed to exist.

The disadvantage of abandoning concrete installations has been assessed in connection with the decommissioning of Frigg. Leaving such structures in place without cutting them down would have a moderately negative impact on free movement for shipping. To ensure such freedom of movement, it has been calculated that an installation must be cut down to 55 metres beneath the sea surface.

The Ministry of Petroleum and Energy has earlier estimated the risk of collision between ships and an abandoned concrete installation as small compared with the risks of removal, providing navigational aids (including lights and electronic signposting) are placed on the installation. It also requires that the position be updated in electronic charts and navigational databases.

4. Disposal on land

Transport from the field to land has been studied in other reports, and is not covered in this section. Reference is also made to other sub-reports which discuss space and locational needs related to technical requirements for breaking up on land.

4.1 Area requirements

Bringing a redundant concrete installation ashore would require considerable space both for the structure to be broken up and for all the activities generating waste products (concrete, marine growth, rebars/metal, etc) with associated volumes which require intermediate storage before further disposal.

The area occupied will relate to the following main activities:

- demolition work in the sea off a receiving facility
- demolition and landing alongside a quay or in a dry dock
- storage of waste hazardous to health and the environment from the installation
- demolition, cutting, blasting, crushing, sorting and internal transport on work surfaces
- intermediate storage of waste products for further disposal.

4.1.1 Area requirements in the sea off the receiving facility

A zoning plan must be in place before a receiving facility can be established. This plan must take many considerations into account in order to avoid future conflicts. All users of the land and sea area (buildings, conservation areas, fish farms, etc) must be included in the planning process in order to clarify important and relevant considerations related to the possible establishment of such an activity.

Large concrete installations standing in the sea off the receiving facility could affect aesthetic values, but safety and the danger that the structure is left untouched must also be assessed.

The space occupied will relate directly to the sea area which must be closed to general access, primarily for safety reasons. But barges/sundry vessels will also shuttle between the temporary site of the installation and the quay in order to land concrete modules, blocks or smaller parts. This will also represent an “area occupation” in terms of increased vessel movements in the immediate vicinity of the facility.

Space will also be occupied, with associated environmental consequences, by certain activities such as underwater blasting. Tanks and shafts may also need to be cleaned [xxix], with possible challenges related to waste and drill cuttings on the upper cell domes [xxx].

4.1.2 Area requirements related to quays or dry docks

The size of a concrete installation will in itself require that a quay or dock where the work will be done is of a commensurate size and has systems which can handle waste generated in compliance with the regulations.

Many metres of quay will be a big advantage at a receiving facility. This would allow a number of activities to be pursued simultaneously, enhancing the efficiency of the various jobs associated with breaking up, landing (crane/vessel) and not least further processing for appropriate handling of the various waste components. The area occupied will relate to the quay and possibly a dry dock where the work is done. Should large areas be available on the landward side of the quay, it would substantially boost the efficiency of the planned operations [xxxi].

4.1.3 Area requirements for storage of waste hazardous to health and the environment

As an installation is prepared for breaking up (in the sea off the receiving facility or at the quay/in a dry dock), intermediate storage will be required for waste hazardous to health or the environment, such as oil, drill cuttings, cell sediment, oil drilling slops and washwater.

Various area classes for the different activities planned have been adopted in connection with the construction of the receiving facility at Vats and the emission application for the facility at Lutelandet [xxxi]. This includes a specification of the different activity areas with requirements for installations and treatment equipment. Typically, a threefold division will be adopted:

- area class A: space for storing, processing and cleaning of polluted waste with security measures to prevent the emission/discharge of environmental toxins
- area class B: space for receiving, storing, sorting and processing waste which requires the handling of oily slops and surface water
- area class C: spaces without specific requirements for treatment facilities, such as areas for reception and intermediate storage of waste which is not hazardous to health and the environment, as well as vehicle movement and parking areas.

In addition to area classes for the various types of waste, tankage will be needed for temporary storage of liquid waste components before these are sent to approved treatment facilities. This must include tanks for intermediate storage of various liquids (such as slops, oily washwater and drill cuttings with associated oil fractions) removed from modules, piping, tanks, etc, before cleaning and breaking up can begin. Tankage should also be planned to store fuel required by machinery at the facility. These tanks must stand in area class A and be built in compliance with applicable regulations.

Alternatively, contaminatedwater can be collected in tanks on the platform topsides or in a support ship. The report on *Disposal of concrete installations* states the following in chapter 8.3 [xxx]:

“If the storage cells have been used for oil storage and these are not to be cleaned offshore, polluted water must be collected in tanks on the platform topside or in a support ship. Depending on the preconditions applied for refloating, it could be necessary to clean oil storage cells before refloating/transporting the platform. This is done to avoid pollution in case [the installation] is wrecked during the tow. Great uncertainty exists over the amount of oil in the cells, primarily because of the difficulty of access to carry out investigations. A method for entering the cells is required. Several trials have been conducted on Brent in the UK sector, including the sending of mini-ROVs through existing piping, but none have been entirely successful. Mechanical outfitting and methods for cell cleaning are not covered by this report. It is nevertheless clear that it would be simpler to clean or treat the storage cells in another acceptable manner if the platform is removed to land and the topsides are removed.”

Intermediate storage for hazardous waste would largely be in area class A, while area class C would probably be sufficient for storing clean broken-up concrete and rebars.

4.1.4 Area requirements related to breaking up

Experience from receiving facilities is that lack of temporary storage areas represents the big bottleneck. When planning new facilities, large areas should be provided for receiving, storing and processing several installations simultaneously, and thereby create simpler and more sensible solutions with regard both to the use of labour and to logistics and various work operations which require specialised expertise or equipment.

Furthermore, area requirements for the actual work of demolishing, cutting, blasting, crushing, sorting and internal transport on work surfaces must also be assessed in relation to environmental impacts, particularly with regard to noise. Positioning of the facility and its area requirements will call for a detailed assessment of noise sources within it. The space required accordingly relates not only to the facility’s own “footprint” but also to how large an area will be affected by undesirable levels of noise.

4.1.5 Area requirements related to intermediate storage before onward disposal

Large industrial areas will be required, which are capable of handling the volumes of the main components from demolition – concrete, rebars and marine growth.

The need for extensive space to hold concrete (whole sections/crushed) in intermediate storage will to a great extent determine area requirements. For comparative purposes, it can be mentioned that a solid concrete block measuring 1x1x1m (one cu.m) corresponds to about two-three cu.m when crushed into small fractions. This means that an installation like Statfjord A, with a (concrete) weight of about 200 000 tonnes [xxxii], will generate 400-600 000cu.m of crushed concrete.

The area required for intermediate storage of, say, 50 per cent of Statfjord A's concrete could total 10 hectares. That would store 200-250 000cu.m in a "pile" covering 100x100m and standing 25m, corresponding to an eight-storey building on two football pitches. It will accordingly be very important to dispose of the concrete as it is cut up or crushed.

4.2 Dust, noise, emissions to the air and discharges to water

Work on demolishing large concrete installations on or adjacent to land will involve noise, emissions to the air and discharges to water. The commonest activities involved in disposal on land are presented in this chapter.

It is assumed that the installation taken to land (quay, harbour or receiving facility) has been stripped of its topsides and that all possible waste hazardous to health and the environment has been removed in conformity with the regulations before the installation is taken to land.

This means that, on arrival at the receiving facility, the structure will consist only of reinforced concrete polluted to varying degrees with various substances hazardous to health and the environment, marine growth and equipment required for the tow to land.

The main activities, which should be conducted in the following order, which affect emissions/discharges will therefore be

1. environmental reconstruction – removal of all waste hazardous to health and the environment
2. removal and treatment of marine growth
3. demolition (chopping/blasting/breaking up) of the actual concrete structure.

Each of these main activities embraces countless subordinate activities. It is emphasised that site/project-specific activities will be needed in many cases in order to conduct all the operations related to disposal of concrete installations on land.

4.2.1 Environmental reconstruction

Environmental reconstruction involves the removal of waste hazardous to health and the environment from installations for intermediate storage and delivery to an approved recipient or processor.

Substances hazardous to health and the environment can be found in such materials as drilling waste (slops, oily washwater and drill cuttings with associated oil fractions), mud and sediments with oil residues, heavy metals and low-level radioactive compounds. There may also be ballast sand in storage cells, drill cuttings and mud in risers, and so forth. Identifying and classifying the various waste fractions and volumes will be necessary before and during environmental reconstruction.

The ideal solution could be to remove all waste hazardous to health and the environment offshore. However, a number of reports have found this to be unrealistic [xxx]. Even if storage tanks, etc, have been extensively cleaned before towing to land, sediments and other deposits/precipitates could have a high wax content and therefore adhere strongly to concrete and possible other structures. Deposits/precipitates are also likely to be relatively immobile (because of a high wax content) and will remain stuck in pores in internal tank walls.

Virtually all environmental reconstruction activities will relate to cleaning.

- **Removal/cleaning** of various objects/installations (piping, risers, hoses, modules, tanks (cells) and equipment) which will probably contain residues from slops (oil drilling waste), washwater, cleaning agents, process water, drilling mud, scale, etc. In some cases, cleaning will involve the use of chemicals and should then be conducted in enclosed facilities.
- **Water treatment.** Slop fluids and washwater brought to the receiving facility or generated during cleaning must be treated so that the end product can be disposed of acceptably and in accordance with the regulations. The end product is regarded as hazardous waste. Washwater will probably be polluted with both oil and heavy metals as well as with possible substances from cleaning agents or other chemicals. These must be removed before discharge.

Great uncertainty prevails about the quantity of oil in tanks (cells), primarily because of limited access for investigations on the actual installation. It could be simpler to clean the storage cells or to treat them in another acceptable manner if the installation is taken to land and the topsides removed.

The environmental consequences of these activities with associated discharges are discussed in a later chapter.

4.2.2 Removal of marine growth

Marine growth directly on clean concrete has a limited environmental impact. It is growth related to possible polluted coatings or concrete containing substances hazardous to health or the environment which could lead to undesirable environmental impacts [xxxvii].

Water-jetting and mechanical methods such as scraping and brushing are the commonest methods for removing marine growth. The removed waste comprises barnacles, scallops, seaweed, kelp, dirt and coating, which can in turn be a source of odours in a receiving facility. This may affect discharges to water and possible noise for the surroundings.

When removing growth at a quay, collection systems should be established and booms installed around the installation. Fabric collectors, nets or the like should be installed to prevent growth sinking to the seabed. Collected growth can then be delivered for processing to biological material. The same applies to material collected if removal occurs on land.

Various methods have been assessed for processing marine growth into biological material. It would first be necessary to remove surplus water before decay begins. Mechanical dewatering is relevant for producing a more easily-handled material. The water removed must be treated to remove solid particles through sedimentation, possibly with a sieve/filter for organic material in suspension. Clean water can be discharged to the sea.

4.2.3 Demolition of concrete installations

Technical aspects of disassembling/demolishing concrete installations are covered in other sub-reports.

Work on breaking up, crushing, splitting and/or blasting concrete installations will create dust and noise which can be compared in many respects with corresponding activities in quarrying, tunnelling or other construction work. This covers such activities as

- breaking up reinforced concrete with a hydraulic chisel hammer
- crushing concrete in a crushing mill (various types exist)
- sawing/cutting reinforced concrete with a diamond saw/wire
- sorting rebars/concrete and the grain size of crushed concrete

- drilling in reinforced concrete with associated blasting
- operating cranes and diesel-driven vehicles
- cleaning equipment
- loading and unloading
- transport of spoil before and after treatment.

Modern mechanical equipment can cut up large parts of the reinforced concrete.

Methods for blasting concrete while also separating out rebars have been investigated. This could simplify the work considerably [l]. But the method needs considerable development with regard to both HSE and more complex reinforced concrete sections.

Blasting is regarded as relevant for demolishing concrete installations in order to break them up into smaller sections/modules, and can be conducted under water.

4.2.4 Noise

Noise will be closely associated in particular with the work of breaking up, crushing, splitting and blasting concrete installations. Other noise sources will include cranes and diesel engines as well as traffic and cleaning activities.

Noise impact

Noise is closely associated with the activities at a facility for breaking up concrete installations. It can be disturbing for everyone in the area. The scope of such disturbance often depends on whether the facility is established before or after homes, holiday cabins or other workplaces have been constructed, and their proximity to the receiving facility.

Exposure to workplace noise can be harmful for employees. Hearing loss is one of the commonest consequences of work-related noise. The latter can also cause stress and therefore help to boost accident risk [xxxiii]. The effects of noise could include full or partial deafness, tinnitus, increased risk of accidents, communication disruptions and stress.

Requirements and guidelines

Applicable guidelines for dealing with noise in the area planning process are provided by the T-1442 document [xxxiv] from the Ministry of the Environment. The guidelines have been prepared in line with the methods and dimensioning values in the EU regulations, and are coordinated with the noise rules specified pursuant to the Pollution Act and the technical regulations in the Planning and Building Act. T-1442 must be applied in area planning and when considering individual cases pursuant to the Planning and Building Act in local authorities and affected government agencies. It applies both when planning new noisy activities and when specifying the size of buffer zones against noise around existing operations. The guidelines also embrace provisions on limiting noise from construction activities.

The division of buffer zones for noise around industry, ports and terminals are shown in table 1. Noise from such activities should not exceed the limits in table 2. The noise limits in the table vary, depending on whether the sources are characterised as impulse noise. The limit for industrial impulse noise should also be used for noise perceived by the hearer to have a clear sinusoidal tone. Experience of activities which could occur in a facility for breaking up concrete installations indicates that impulse noise will be generated.

The limits for equivalent levels shown in tables 1 and 2 are averaged over a year. However, the noise level for a single working day should not exceed the recommended annual average by more than 3dB.

In addition to the general requirements and guidelines for noise, a receiving facility will be given an emission permit by Klif which sets specific rules for the plant concerned.

Table 1. Division of noise buffer zones pursuant to T-1442.

Noise source	Noise buffer zone			
	Yellow zone		Red zone	
Industry, ports and terminals	No impulse noise: L_{den} = 55dB Impulse noise: L_{den} = 50dB	L_{night} = 45dB L_{5AF} = 60dB	No impulse noise: L_{den} = 65dB Impulse noise: L_{den} = 60dB	L_{night} = 55dB L_{5AF} = 80dB

Table 2. Recommended noise limits when establishing new noisy activities and building homes, hospitals, nursing homes, holiday homes, schools and nurseries. All figures in dB, free-field values.

Noise source	Noise level at outdoor sites and outside rooms for noise-sensitive use L_{den}	Noise level outside bedrooms, night-time 23.00-07.00	Maximum noise level at outdoor sites and outside rooms for noise-sensitive use, 07.00-23.00
Industry, ports and terminals	No impulse noise: 55dB Impulse noise: 50dB	L_{night} = 45dB L_{5AF} = 60dB	-

Noise reduction measures

The following measures are among those available for reducing noise at a facility:

- purchasing the quietest possible machinery and equipment, and maintaining it regularly
- preventing noise spreading from its source by such means as screening, encapsulation and damping down noise through walls, roof and floor
- protecting the individual employee in line with the noise guidelines and the Working Environment Act
- regular measurement of noise in workplaces and in the neighbourhood.

Opportunities for reducing the noise level are good when planning new receiving facilities, and should be given high priority when designing these.

4.2.5 Emissions to the air

Emissions in this case primarily involve exhaust fumes from various vehicles and vessels needed in the various operations, as well as dust from transport and from crushing/demolition.

Emissions will be confined to ordinary emissions from vessels, machinery and equipment which are mainly powered by diesel oil as fuel and are connected to the activities described above. Work related to environmental reconstruction – i.e, removal of substances hazardous to health and the environment with associated treatment (such as incineration) of hazardous waste – will also produce emissions. Removal of marine growth with associated treatment could lead to odours related to emissions.

Given that the facility will primarily receive, demolish, sort and deal with concrete, dust could be a substantial problem.

Environmental impact of emissions

Offshore-related studies show that breaking up/crushing concrete will consume substantial amounts of energy, with associated CO_2 and NO_x emissions, compared with production of aggregate from a conventional quarry. This also applies to energy consumption with associated emissions for breaking up/crushing concrete to recover rebars, compared with extracting iron ore from mines.

The environmental impact of emissions from both fuel consumption and incinerators for hazardous waste has been assessed in countless reports.

Emissions from fuel consumption will be discussed further in later chapters of this report.

Environmental impact of dust

Breaking up, crushing and possible blasting, as well as road traffic on site, contribute to dust dispersal from a facility. Dust from the actual blasting of concrete structure can be a great nuisance. If none of the proposed measures are implemented before and during the blasting, the smallest particles will be dispersed up into the air and carried away by the wind.

The impact of dust dispersal from a receiving facility on the immediate environment is expected to be limited if the various measures proposed are implemented and function satisfactorily. Measurements of dust settlement and suspension will show if the measures are good enough.

The environmental impact can be divided broadly as follows.

- **Run-off/natural environment:** rock dust from the facility could influence the environment along the shoreline or in a littoral basin, and cause eutrophication and increased sedimentation from dust particles. See also the environmental impact of water discharges.
- **Aesthetics**: dust particles settling on vegetation and in the immediate neighbourhood is normally undesirable. With high annual precipitation in the area (western Norway), dust which settles on land, plants and trees will be washed off, so that large amounts would be needed to leave permanent traces
- **Neighbours/working environment/health:** measurements will be needed to ascertain that workers and/or neighbours are not being exposed to concentrations of suspended dust above the specified limit values.

Requirements and guidelines for emissions and dust

General requirements and guidelines exist for emissions from enterprises operating receiving facilities for redundant offshore installations. Emissions can have various significant negative effects, with local, regional, national and/or global impacts. The most important requirements and guidelines are those related to emissions of CO_2 and NO_x from machinery and equipment.

The pollution parameters for emissions from incinerators burning hazardous waste yielded by redundant concrete installations, for instance, are TOC, HCl, SO_2, NO, NO_2, heavy metal compounds and dioxins.

When incinerating slops, the requirements in chapter 10 of the waste regulations must be met.

In addition to the general requirements and guidelines which exist for emissions and dust, receiving facilities will be given an emission permit from Klif which sets specific rules for the plant concerned.

Regular measurements of dust exposure for personnel engaged in the various activities should be conducted at receiving plants where concrete is to be broken up, crushed and separated. These could include sampling dust deposition and in suspension, for example.

Dust deposition (monthly mean value)

Chapter 30 of the pollution regulations apply to companies producing crushed aggregate, gravel, shingle and sand.

Section 30.5 specifies that emissions of rock dust/dust/particles from the total activities of an enterprise must not cause the volume of deposited dust to exceed 5g/sq.m over 30 days. This applies to mineral content measured at the nearest neighbour or other neighbour who may be more affected.

According to section 30.9, enterprises less than 500m from the nearest neighbour must measure dust deposition at 30-day intervals. The measurements must last for at least a year, and must not cease before they document that the requirements of section 30.5 are met.

The values applied today (2011) by Nilu when assessing dust loads are:

- very high >13g/sq.m per 30 days
- high 8-13g/sq.m per 30 days
- moderate 3-8g/sq.m per 30 days
- low <3g/sq.m per 30 days

The daily ceiling for suspended dust from an enterprise measured at the plan boundary is 50µg/cu.m dust with particle diameters < 10µm (PM10), and must not be exceeded more than 35 times (days) per year. The annual mean value must not exceed 40µg/cu.m.

Measures to reduce emissions

Machinery and equipment should be of standard quality and subject to a maintenance programme which ensures that emissions are minimised. Machinery with good operating economics should be given preference.

The possibility that machinery and equipment would become more environment-friendly by converting to electric drive should be kept under continuous assessment.

Offshore cleaning of tanks and equipment is crucial for reducing the work of cleaning, storing and treating substances hazardous to health and the environment on land. Treatment – in practice incineration with associated emissions – can therefore be reduced by minimising the amounts which need to be handled/incinerated on land.

Activities must be organised in such a way that dust is not released from the processing or storage area. All activities which may involve appreciable dispersal of dust outside the area should be conducted indoors (if possible) or with other mechanical screening against dust dispersal. If this cannot be done, the following should be considered as possible solutions:

- use of dust masks in the dustiest activities
- vacuum collectors to suck up dust when drilling and/or sawing
- use of nozzles to spray water over objects to reduce airborne dust
- use of sprinkler systems to reduce dust levels in the dustiest areas (breaking up/crushing)
- asphalting areas or providing other solid surfaces
- regular cleaning of machinery and areas for vehicular traffic
- spreading salt and/or water on areas for vehicular traffic, particularly on dry days
- buildings should be washed if this proves necessary.

4.2.6 Discharges to water

Activities which will primarily affect discharges are closely related to the areas used for demolition of a concrete installation. Run-off from this work could be controlled in part by installing impermeable surfaces with membranes and collection systems.

Pollution of the natural environment through discharges to water could occur from such sources at a receiving facility as

- outlet point for discharge pipes
- oil separators with drainage tanks/sand traps
- cleaning

- storage tanks on the concrete installation
- tanks at the receiving facility
- discharges from vessels involved in landing operations
- hazardous waste storage
- run-off.

Environmental impact of discharges

The environmental impact of discharges to water from a receiving facility relates in part to the size of the run-off from the plant. The latter should basically be designed to ensure minimal run-off – i.e, by specifying impermeable surfaces with membranes and passing all run-off through an oil separator to a treatment plant. Discharges will then depend on the efficiency of the oil separator/treatment plant – i.e, the quantity of inorganic (heavy metal) and organic (oil, PAHs, PCBs) environmental toxics released.

Looking at the impact of releasing environmental toxins from the receiving facility, experience has shown that such substances are often bound to particles and settle as seabed sediment. Benthic (bottom dwelling) animals and fish living close to the seabed will thereby be affected by the pollution, depending on its concentration and the duration of discharges.

Certain organic environmental toxins (PCBs) accumulate in the food chain.

Fine particles and dust from crushing and blasting may contain nitrogen, and run-off from the facility could lead to eutrophication of the recipient. It can also contribute ammonia to the water and fertilise the surrounding areas. In addition, it could add more suspended particles to the water and create problems for fish and other organisms.

Sediments suspended in the water can destroy visibility for hunting birds and fish, and affect organism which filter water.

Increased shipping movements boost the risk of accidents and discharges, with associated environmental impacts. Leaks from vessels could harm the area and disrupt organisms which live there. Major accidental spills could have disastrous consequences for local bird life. Discharges to the sea could have a direct impact on possible conservation areas in the vicinity.

Requirements and guidelines

In addition to the general requirements and guidelines for discharges to water, a receiving facility will be given an emission permit by Klif with specific rules for the plant concerned.

The water framework directive is an EU directive which establishes a framework for water policy. Incorporated in the EEA agreement and thereby also applicable to Norway, it covers all fresh (surface and ground) water as well as coastal waters [xxxv].

Areas where oily waste water could occur are subject to chapter 15 of the pollution regulations, which includes requirements for an impermeable surface with run-off to a sand trap and oil separator. It is important that these are adequately dimensioned.

Hazardous waste must be handled, temporarily stored, declared and delivered to an approved reception plant pursuant to the waste regulations. Chapter 11 of the latter on hazardous waste aims to ensure that such materials are treated in an acceptable manner.

Details can be found in the following documents (in Norwegian)

- *Håndtering av farlig avfall*, SFT guideline TA-2023/2004.
- *Farlig avfall: Veileder om innlevering og deklarering av farlig avfall*, Norsas 2009.

Pollution parameters

Pollution parameters which could occur in water from a typical receiving facility include:

- total hydrocarbon (THC) – i.e, benzene, toluene, ethylbenzene and xylenes (BTEX) + oil with four intervals (C6-C35)
- heavy metals, such as arsenic, lead, cadmium, copper, chrome, mercury, nickel and zinc
- polycyclic aromatic hydrocarbons (PAHs)
- polychlorinated biphenyls (PCBs)
- chloroparaffins
- brominated flame retardants (BFRs)
- phthalates
- low-level radioactive waste (LRA)
- total organic carbon (TOC)
- ammonium
- nitrates
- phosphate

Measures for reducing discharges to water

Relevant measures for reducing or eliminating discharges to water could include:

- designing the facility so that activities related to ordinary and hazardous waste are managed acceptably, without a danger of run-off or infiltration of the soil
- the facility must have an efficient collection system and its own treatment plant for polluted water, including surface water
- oil separators with sand traps and filters must be installed to safeguard against oil spills to water.

Relevant activities to check that these measures are functioning could include:

- emptying sand trap tanks, oil separators and collection tanks for oil in accordance with specified procedures
- establishing a specific sampling and analysis programme for the most relevant discharge components/pollution parameters at all discharge points
- preparing and pursuing an environmental monitoring programme for sediments and recipients outside the facility
- developing emergency preparedness plans, in part on the basis of environmental risk analyses.

4.3 Deposition and recycling of materials

The *Decommissioning Offshore Concrete Platforms* report summarises the various products/fractions/aggregates which can be derived from a concrete installation [xxxvi].

Information has been obtained about current practice for the disposal of demolished concrete on land. Assessments have been made about the extent to which concrete from offshore operations can be deposited on land, with substances hazardous to health and the environment which have stored in cells/tanks taken into account.

These assessments also relate to the use of crushed concrete as aggregate, recovery of rebars and not least the environmental impact of using crushed concrete versus extraction/crushing of blasted rock from conventional quarries.

4.3.1 Introduction

Deposition and recycling of materials are closely related to the way waste handling at a receiving facility is prioritised and organised. Natural goals and priorities related to waste handling include conforming with national goals and strategies. According to the waste regulations [xxxviii], this involves "promoting environmentally and socio-economically acceptable handling by the building and demolition industry, and preventing illegal disposal of such waste". Another obvious goal will be to meet all requirements from government and customers, and the health, safety and environmental requirements pertaining to employees and the natural environment.

Many different types of waste will be generated at a receiving facility, and the latter must accordingly be organised to handle such variety.

From an environmental and resource perspective, the waste must be handled in the following order of priority:

1. reuse
2. material recycling
3. energy recovery
4. deposition.

Reuse means that the product is used again in its original form and normally requires no permission. A condition for reusing a product is that it contains no substances or materials hazardous to health or the environment which are currently prohibited, such as mercury, PCBs or asbestos.

Material recycling: for a material to be regarded as recycled, all the following requirements must be met [xxxvii]:

- in its new mode of use, the material must have a function additional to volume – such as insulating properties
- it must be possible to specify properties of the material in advance
- the material must have a value for somebody; its disposition must occur because the recipient has a use for it, not because the supplier needs to dispose of it
- the material must not be polluted by other waste or environmentally harmful components.

Recycled materials can be used without special permission from the pollution authorities providing they and their use satisfy the criteria listed above. Clean, crushed concrete can therefore be used in place of corresponding volumes of crushed aggregate or other fillers.

Energy recovery involves waste incineration. Incinerating waste in modern energy recovery plants converts a disposal problem into an important energy resource.

Deposition is basically not an alternative if the material can be reused or recycled in line with the requirements specified above. All final disposal in the form of waste deposition or burial must accord with the waste regulations, which define a landfill as “a permanent disposal site for waste through its deposition on or below the ground”.

Concrete and steel from a redundant offshore concrete installation will be analogous with comparable waste from land-based construction. The general principle is that all non-hazardous construction waste must be delivered to legal landfills unless it is reused, recycled or disposed of/used in another legal manner. This is discussed in the chapters below.

According to chapter 15 of the waste regulations [xxxviii], substances hazardous to health and the environment must be removed if construction waste is to be recycled. Chapter 9 of the Planning and Building Act [xxxix] specifies the preparation of an environmental reconstruction description and waste plan, in which deliveries of unsorted waste hazardous to health and the environment are documented before demolition begins.

4.3.2 How demolished concrete is used on land today

Generally speaking, concrete from demolition projects can be broken up and used for landfill on the same site providing the rebars are removed and no substances hazardous to health and the environment are present.

Concrete from demolition or rehabilitation is often delivered to a recycling plant for treatment there – crushing into specified fractions, for example. The same applies to concrete residues from casting. With major demolitions, crushing concrete could also be relevant on site for such local applications as road bases or foundations for new buildings. Mobile crushing plants are also relevant where the distance to the recycling and/or crushing plant is considerable.

Publication 26 from the Norwegian Concrete Association is an important base document [xl], and covers the use of recycled aggregate in concrete. Such usage with associated quality criteria is considered in a later chapter.

Most demolished concrete in Finland is used as landfill. Crushed concrete has been described as ideal for this purpose, since it contains unreacted cement and will therefore harden in use to provide a greater/better load-bearing capacity [xli].

The USA’s Recycled Materials Company Inc has specialised in recycling concrete and asphalt. It can deliver such products as road bases, coarse aggregate, drain rock, structural backfill, landscape stone, vehicle tracking rock, surfacing materials, under slab bedding, drain rock, washed aggregate and path/yard gravel [xlii].

4.3.3 Reusing concrete

In this context, reusing concrete means that all or parts of the structure are broken down into smaller modules, blocks or sections, which are reused without crushing the concrete. Specific proposals for such reuse are presented and briefly discussed in chapter 4.4..

A number of challenges are presented in reusing concrete from concrete installations. First, the sections/blocks/modules must be cut or separated without being damaged, and then lifted and transported without worsening the properties of the reinforced concrete to any appreciable extent. Second, product liability will be an issue with regard both to safety and durability. That could reduce sales opportunities for the concrete sections [l]. Where durability is concerned, it should be noted that concrete strength increases with age [xlixliii]. Intermediate storage of “finished” concrete sections/blocks which have not been sold or used will be challenging in terms of both cost and space required.

4.3.4 Recovering concrete materials

As mentioned above, the environmental impact of operations/activities for concrete crushing and recycling relates primarily to dust and noise. Concrete crushing allows rebars to be removed, collected and delivered for recycling by approved recipients.

Environmentally, recovering/recycling of concrete offers both advantages and disadvantages.

The primary advantage is that recycled concrete can supplement quarried aggregate, which reduces consumption of non-renewable resources (crushed aggregate, sand, etc) and also extends the life of the quarry. Filling up landfills is also avoided, while transport requirements are reduced. In some cases, concrete recycling could also reduce energy consumption and emissions.

Disadvantages of recycling may relate to increased noise and dust emission/discharge, as well as to transport by ship or vehicle in sensitive areas.

The amount of concrete which could be generated from redundant concrete installations will vary between 120-550 000 tonnes per installation, which is in the same order of magnitude as Norway's total annual volume of quarried rock. This crushed concrete can be used for many purposes, locally, nationally and internationally, depending on market demand [xl].

According to a report from the NPD [xliv], many relevant applications and markets exist for the various products:

- **finely crushed material**, depending on grain size and quality, is used as aggregate in new concrete and asphalt, as road bases or as various types of infill
- **coarser material** from crushed concrete is used for infill, depending on grain size and quality
- **large reinforced concrete sections** can be used in erosion protection, for example
- **modules/rings** can be used in the fish farming industry (concrete tanks) or as the base of wind turbines.

Finely crushed material

After crushing, sifting and sorting, the crushed concrete is separated and graded by size and customer requirements. Depending on the kind of concrete and type of plant crushing it, various grades of sizes/products will be produced for the market. Clean sorted concrete is ideal for construction and building foundations. It can also be used for road bases, drain rock and backfill against walls, and as infill and bases for roads, car parks, etc. Standards are set for aggregate when producing new concrete [li]

- **Finely crushed material 0-4mm:** 20-30 per cent of crushed concrete is expected to fall into this category. It can be used as aggregate in asphalt, but not in new concrete. Deposition is also an option.
- **Medium crushed material 4-32mm**: 70-80 per cent per cent of crushed concrete is expected to fall into this category. It can be used for insulation in landfills, road bases or aggregate in new concrete if its quality is acceptable. Proposals have also been made for using this material to cover pipelines in the North Sea.
- **Coarser materials 32-100mm**: for other applications, such as infill, standards exist for the use of crushed concrete. Should crushed concrete be used for infill, the grains must be hard, granulated, drainable and chemically inert while being decompressible. Nor must alterations in air humidity cause changes in grain dimensions [l].

Concrete sections/blocks

A fully acceptable alternative to crushing the concrete is to produce reinforced concrete sections/blocks/pieces of varying size, depending on the purpose. They can, for instance, be used for erosion protection or for shoreline reinforcement. Possible methods for producing these include:

- cutting modules/rings of 200-400 tonnes apiece from shafts or cells/tanks with the aid of a diamond saw/wire or special blasting systems
- transport from mooring site/quay/dry dock with the aid of crane or barge to a dedicated area to be cut up

- cutting into sections/blocks depending on requirements/purpose, such as blocks of 0.3 to six tonnes (see the example in chapter 4.4.)

Large areas will be needed for intermediate storage of various sizes before delivery to customers.

Solutions must also be found to the exposure of rebars by cutting. Corrosion is a threat if the concrete is to be used for shoreline reinforcement, and poor durability would have to be considered before use [xlv].

Another perspective will relate to the ethics of using concrete blocks for such purposes. Will this be an acceptable solution for future generations?

Quality criteria for recyclable concrete

As mentioned above, recycled/recovered concrete must be suitable for specific applications [xxxvii]. The crushed concrete must accordingly meet certain standards for grain size, physical properties, stability, durability, and possibly its content of limited concentrations of substances hazardous to health and the environment. If crushed concrete is to be used to make new concrete, a number of factors will determine whether its quality is acceptable [xlv]:

- size (standard example 0-32mm)
- quantity of mortar and cement in possible aggregate
- density of material/aggregate
- ability to absorb water
- crushability
- load-bearing capacity
- sulphate content
- possible pollutants.

Many documents specify requirements for concrete to be used for various applications. This is discussed in detail, for example, in a report from the US Army Corps of Engineers [xlv].

Deposition of/infill with clean demolished concrete

Demolished concrete can only be used for infill if it can be documented that this material is not polluted or that its use presents no health or environmental hazards [xlvi].

Disposition/use of polluted demolished concrete

Concrete here means both material cast in situ and prefabricated concrete elements. The main components are cement, sand and water. These do not normally contain environmentally hazardous substances [xlvii].

Concrete from a redundant installation, particularly the surface of internal walls in tanks and cells, may be polluted with many substances hazardous to health and the environment, such as inorganic environmental toxins (heavy metals), oil, PAHs, PCBs and other organic environmental toxins. The scope of possible pollution must be assessed in each case.

The pollution regulations specify norm values for the commonest inorganic and organic environmental pollutants. If concentrations exceed these values in the concrete, a risk assessment must be carried out for disposal of the polluted material. This means, for example, that if the PCB content in coating, plaster or filler employed on the concrete exceeds the norm value, the concrete cannot be used for infill unless the PCB-containing coating, plaster or filler is removed [xlviii].

Polluted concrete may rank as hazardous waste if the content of environmental toxins is extensive. Clarifying how deep possible pollution has penetrated into the concrete is crucial.

This can be done by coring and chemical analysis of the relevant environmental toxins at various depths from the surface and in. Such a sampling programme will form part of a possible application to dispose of concrete from a concrete installation.

It is important to be aware that a number of types of construction waste, such as lightly polluted concrete, must be subjected to special handling, even though the concentrations of the relevant pollutants are below the limits for hazardous waste.

If demolished concrete contains extensive pollution – i.e, concentrations above the limits for hazardous waste – it must be delivered to an approved receiving plant for hazardous waste. See chapter 9 of the waste regulations on waste deposition and chapter 11 on hazardous waste [xxxviii].

In concrete polluted by oil, experience has shown that the oil concentration can vary considerably with concrete depth and that this is closely related to the type of oil present, the duration of its contact with the concrete, and concrete strength. Experience from risk assessments related to polluted demolished concrete is that potential exposure will be minimal if the concrete is covered by an impermeable layer or by clean material. This is primarily because the oil will become bound with the concrete.

Recovering rebars

A 1996 report from *Dames & Moore* [xlix] notes that many challenges are presented by separating rebars when crushing. On the other hand, the quantity of rebars which can be recovered is large and must be viewed in relation to the alternative of mining iron ore with associated industrial processes to manufacture reinforcement iron.

One example is the Gullfaks A concrete GBS, which contains some 130 000cu.m of concrete with roughly 270kg of rebars per cubic metre of concrete. That means a total of 312 000 tonnes of concrete and about 35 000 tonnes of rebars [l].

Crushing the concrete allows the rebars to be removed, cut into acceptable sizes, collected and delivered for recycling at an approved plant. The volume of unsorted rebars will be in the order of 10-15 per cent of the concrete weight . [xlvii]

Unlike most of the waste materials, recovered rebars could represent a good source of income [xlix].

Energy consumption associated with recycling concrete

A 1996 report from the NPD [xliv] on recycling and recovery concludes:

“Assuming successful execution of removal operations and demolition at the quay and on land, the environmental impact is no greater than from corresponding facilities for producing new material from a gravel pit/quarry. ... No detailed assessment has been made of the energy consumption associated with the work operations described for recovering and/or recycling components or materials from a concrete installation. This has not been possible on the basis of the available base material. However, estimates indicate that energy consumption will not differ significantly from conventional production of concrete blocks, stone or aggregate. The variation in energy consumption will be in the order of +/- 0 when the transport element is disregarded. Transport (from the production site to the market) could represent a significant energy factor in both positive and negative direction, depending on the market conditions and operating parameters applied.”

A study conducted by *Dames & Moore* and *Reverse Engineering Ltd* in 1997 [l] compared the energy consumption from crushing concrete for use as aggregate with the production of aggregate from a quarry. The report concluded that

“experience of removing and breaking up/crushing concrete installations is lacking, so that little specific data exists in the area. For that reason, it is very difficult to calculate energy consumption for the two options: concrete crushed for aggregate or new aggregate from a quarry. Note that concrete deposited in landfills can be retrieved and crushed for aggregate. This could cut energy consumption by up to 20 per cent compared with producing new aggregate from a conventional quarry. Crushing concrete from an offshore installation would be a different challenge because of more rebars and the concrete strength of the installation. The conclusion is that a great need exists for more studies in this area."

The report presents a clear execution model for calculating energy consumption in the two alternatives. Through examples, it shows that concrete recycling/crushing requires roughly twice the energy consumption per tonne of extraction from a quarry. The largest energy consumption of all operations related to the recycling alternative was landing/discharging concrete from a vessel to the crushing plant with the aid of diesel-powered cranes. The report emphasises that great uncertainty exists for all the variables which must be taken into account in order to compare the two alternatives.

For the Norwegian position, the question of whether using crushed concrete is sensible must be assessed in the light of the fact that Norway has many quarries close to the market, and thereby has less of a challenge in securing the resource. Crushed concrete could therefore be more useful as a filling material where the areas requiring it are close to a receiving facility, and providing no quarry exists nearby

4.4 Alternative applications on land

Extensive searches have been carried out in various fora (internet/trade press/internal networks) to identify specific examples of reusing concrete sections/structures. The search strings used are:

- reuse, concrete
- reuse, concrete, -sealing
- reuse, concrete, mole
- reuse, concrete, pier
- ombruk, betong
- ombrug, beton
- wiederverwendung, beton.

Very little information on the internet covers the reuse of concrete in large modules/sections. Examples have been found of reusing concrete slabs which are produced by a crushing process and contain no rebars. This could also involve the reuse of concrete slabs which have not previously been reinforced and which have only been used for concrete paving or outdoor concrete decks.

Alternative applications of the concrete could include erosion or shoreline protection. Concrete installations could also be considered for use as bases for wind turbines or as concrete tanks. Condition assessments and methodology in order to say something about the economic life and structural integrity of the alternatives must be taken into account and carefully evaluated before they are adopted.

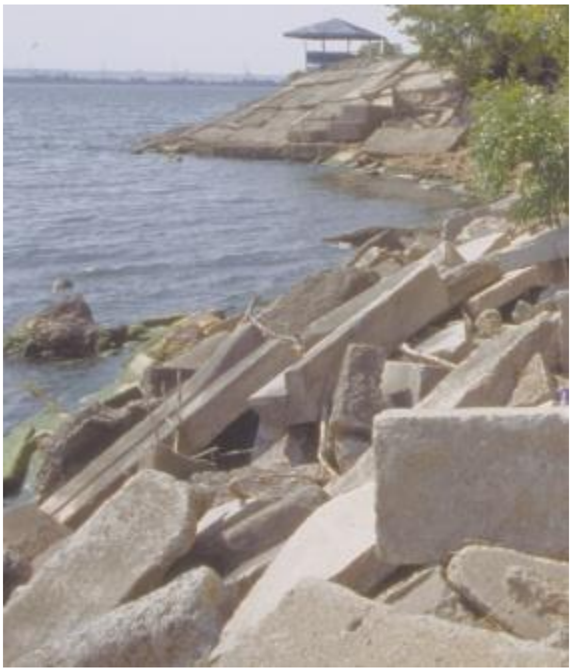

Figure 12. Used chunks of concrete appear to have been employed in the foreground as coarse fill, while concrete slabs seem to be applied in the background to plaster the slope as protection against waves. Source: http://www.dfo-mpo.gc.ca/regions/central/pub/fact-fait-mb/mb3-eng.htm .

Figure 13. Concrete chunks have been used at Queensboro Plaza in New York to create traffic islands and separate such groups as motorists, pedestrians and cyclists. Source: http://inhabitat.com/nyc/jagged-chunks-of-sidewalk-reused-to-create-unique-median-for-queens-plaza/comment-page-1/

5. Energy and environmental account for removal to land versus offshore abandonment

5.1 Introduction

Disposal solutions and associated environmental assessments will often be qualitative in nature and involve some degree of subjective opinion. It is accordingly useful to assess quantitative methods, such as energy consumption and emissions to the air with various operations or solutions.

An energy and environmental account has been prepared for this report covering energy consumption with associated CO_2, NO_x and SO_x emissions for offshore abandonment and disposal on land respectively.

It should be noted that a multitude of different proposals exist for the various sub-operations and the way concrete installations should be removed to land.

Assuming that energy consumption and emissions related to removing the topsides and all other parts of the installation except the gravity base structure (GBS) are excluded, no energy nor further emissions will be involved in abandoning an installation.

For removal to land, however, the installation must first be refloated, then towed to land and brought ashore as modules/sections of varying size before being broken up. Volumes must then be sorted and disposed of either through recycling or by delivery to an approved recipient or landfill.

5.2 Energy consumption for refloating

In principle, the installation is freed by a reversal of the installation process – i.e, the concrete structure standing on the seabed is refloated.

Energy consumption and emissions for these operations have been estimated both in chapter 9 of the Frigg cessation plan [xxvi] and in the Brent Redundant Facilities report [li].

Operations related to the actual refloating are described in more detail in the report on *Disposal of concrete installations* [xxx]. This report states:

"Energy consumption and emissions to the air associated with these operations will relate to special vessels able to conduct this work. Marine operations must be planned in detail, it is proposed here that some vessels will be mobilised but will run on idle until the operation can be executed. Other vessels will be very active throughout the refloating process, and will accordingly make the biggest contributions to energy consumption and emissions."

Furthermore, the Statfjord A report [xxxii] includes a brief description of removing the concrete installation to land/for deposition on land. This includes the following:

"Removal of the concrete installation must be accomplished in the event by deballasting to refloat the platform. Statfjord A was towed out and installed on the field with part of the topsides installed. It is not possible to refloat the platform with the whole topsides as they exist today, and part of the latter must accordingly be taken off before a possible removal of the installation."

5.3 Energy consumption for transport to receiving facility

After the installation has been freed from the seabed and deballasted to its transport depth, it can be towed to the desired location for demolition/breaking up. Uncertainty over weather conditions, leaks and sailing routes is discussed in the report on *Disposal of concrete installations* [xxx].

Energy consumption in the transport operation will relate to the following conditions.

- **The types and number of vessels** towing the installation to land will vary, but transport operations and vessels will be more or less identical with the tow-out of new concrete installations.
- **The distance to the receiving facility**. Several receiving facilities currently exist in Norway. See Klif report TA 2643/2010 on decommissioning of redundant offshore installations [lii]. A new facility is also under construction at Lutelandet [xxxi], just north of the Sogne Fjord.
- **The number of days** the operation is expected to take – i.e, the duration of the tow.
- **The weight of the installation** will be crucial for executing the activities/operations discussed above. In addition to the overall structure, the following elements must be taken into account when calculating weight [xxix]:
    - concrete
    - mechanical outfitting
    - solid ballast in the cells
    - liquid ballast in the cells
    - sedimentation in the cells
    - drill cuttings in the drilling shafts
    - debris on the upper cell shells
    - marine growth
    - cement under the bottom of the cells
    - plugs
    - water absorption in the concrete

Since both weight and distance from the receiving facility will vary, this will represent a major variable which must be assessed when making comparisons. In a specific case, determining total weight will be essential for preparing a sensible energy account [liii].

Moreover, abandonment will be the best solution in many cases both from an HSE perspective and with regard to the environmental impact of removing the installation [liv].

5.4 Energy consumption for landing at/off receiving facility

Landing operations relate directly to breaking the concrete installation up into manageable chunks (modules/blocks/smaller sections) so that they can be taken ashore for further disposal. Energy consumption for such operations from sea to receiving facility relate to the following.

- **Mooring.** Energy consumption for landing at the receiving facility will relate to whether the installation must first be moored and stabilised at a distance from the receiving facility’s quay because of the water depth, or whether it can be brought right to the quayside.
- **Demolition method.** To get the installation on land, it must be divided into modules or large sections. Energy consumption for this will depend on the cutting methods used (such as diamond saw or wire, high-pressure water jetting, thermal lances or explosives).
- **Mechanical handling.** Energy consumption when landing will depend on whether cranes, vessels or a dry dock are used.

This operation is treated as a separate activity because the size of a concrete installation and not least the volumes of concrete and possible ballast and sediments in the cells are very large, and will obviously call for substantial energy consumption. [l].

5.5 Energy consumption for breaking up, sorting and processing on land

Calculations of energy consumption and emissions after the concrete sections have been brought ashore will depend on the methods adopted for sorting, crushing, internal transport (crane, dumper trucks, conveyor belts, etc), and not least onward transport to customers.

A distinction can be made during the actual demolition between reducing the installation to small sections which can be handled by spoil transport (crane with excavating bucket, dumpers or mechanical excavators) or breaking up the concrete components into modules/blocks which can be reused directly as a large module/block [l].

Energy consumption for concrete demolition depends in principle on the overall surface area to be broken up, and thereby on the size and number of resulting fragments. To limit energy consumption, concrete objects can therefore be broken down into the smallest possible number of pieces[lv], i.e, blocks or large modules/rings. When demolishing concrete with a view to recycling it as aggregate, etc, it could be more appropriate to crush it into the largest possible number of fragments during the demolition process.

The report on *Disposal of concrete installations* notes that concrete strength increases with age and can be about 30 per cent above its design strength, depending on the type involved [xxx]. That will naturally affect how difficult it is to crush or blast concrete. On the other hand, it could mean that concrete blocks or sections still have the required durability when being reused for the intended purpose.

Further work on estimating energy consumption can accordingly be divided as follows:

- the concrete installation is broken up and crushed for use in new concrete products/aggregate/infill
- the concrete is only broken up into manageable blocks
- the concrete is broken up into modules/rings.

5.6 Method for estimating energy consumption and emissions to the air

The NPD [xliv] concluded in 1996 that there

"are few reports which deal with the specific environmental impact of removing and breaking up concrete installations. The reports which exist contain a limited set of such information which focuses on energy budgets."

That still applies. The report [xxx] on *Disposing of concrete installations* includes a brief review on earlier work concerned with removing concrete installations. Relevant data on energy consumption to which the report refers can be obtained from reports on the removal of Brent D [li], platforms on Draugen, Gullfaks C and Maureen Alpha, as well as the removal of the Frigg platforms [xxvi].

The UK's Institute of Petroleum has prepared guidelines for calculating energy consumption and emissions [lvi]. This was used with the Frigg cessation plan [xxvi] and the Brent Redundant Facilities [li] reports. Similar calculations have also been performed for BP's Miller platform, which rests on a steel jacket [lvii].

The following estimates/calculations address energy consumption for the various operations in gigajoules (GJ), where the guidelines have been used in part to adapt them to concrete installations. Background information for estimates/calculations related to energy consumption with demolishing concrete have been found in the report on *Recycling of Concrete, Environmental Account.* [l].

5.7 Energy consumption for disposal on land

Estimates of energy consumption include the following operations:

- **mobilisation/demobilisation,** from land to offshore, outbound and inbound
- **refloating of installations**, i.e, removal from the seabed
- **transport** to coastal waters off the receiving facility or to quay
- **landing** to/by the receiving terminal
- **breaking up,** i.e, crushing, sorting and processing .

A summation of energy consumption through all the operations related to the disposal of Frigg TCP2 is presented in table 3. This table is based on the following variables:

- types and numbers of vessels, i.e, use of semi submersible crane vessels (SSCV), multipurpose support vessels (MSV), cargo barges (CB) and supply vessels (SV)
- number of days the operation is expected to take, i.e, the time vessels require for mobilisation, refloating, transport or landing
- displacement of the concrete installation, including ballast
- types and numbers of cranes to be used for landing
- types and numbers of construction machinery used to load the crushing plant, etc
- types and numbers of crushing plants used at the facility
- types and numbers of lorries used for internal transport.

Actual figures for energy consumption (i.e, diesel oil consumption in litres per day) have been found for each of the vessels mentioned above. Actual figures have also been found for energy consumption of cranes, construction machinery, crushing plants and lorries.

Table 3: Summation of energy consumption from disposal of Frigg TCP2 to land.

Operation		Energy consumption, GJ
Marine operations	Mobilisation and demobilisation	**68 000**
	Refloating	**194 000**
	Transport to near receiving facility or to quay	**172 000**
	Landing operations	**74 000**
Demolition		**14 000**
Recycling of rebars		**150 000**
Total energy consumption		**673 000**

General assumptions in the calculations

The following activities are expected to be conducted before the actual removal operation.

- All wells have been plugged and sealed.
- All piping and cables attached to the seabed have been cut.
- All calculations assume that the topsides have been removed and all tanks emptied of oil and/or other liquid deposits – i.e, the installation is in a cold phase. Cleaning of tanks and environmental reconstruction operations are not included.
- All systems on the platform topsides have been shut down, cleared, cleaned and prepared for cold condition.
- A great many variables must be taken into account. No special examples are used because of the great variations in design and methods for refloating/removal, transport,

landing and concrete demolition/processing. General assumptions have accordingly been applied for the operations outlined.

- Calculations related to work and energy consumption/emissions which might arise before the concrete installation is in a cold condition and after it has been broken up into finished sections or large blocks (transport from the receiving facility to the customer, for instance) are not included.
- The calculations are based on the typical time operations are expected to take. It is important to appreciate that technical problems and weather can cause big delays. That would naturally increase energy consumption and emissions.
- Calculations are based on the displacement of the installation with ballast but without topsides. Being able to remove ballast offshore would require further study.
- Mobilisation and demobilisation of vessels for use in the operations are included in the calculations.

5.8 Emissions to the air from disposal on land

The quantitative emissions considered to be most relevant in connection with disposal on land are carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), sulphur dioxide (SO_2), hydrocarbons (HC) and particles [lviii].

Guidelines [lix] have been prepared for emissions from all larger vessel types operating internationally and nationally. This provides guidelines on performing calculations and factors related to emissions. Input data for the emission calculations have also been taken from tables in the Institute of Petroleum's 2000 report [lvi] and from the Brent Redundant Facilities report [li]. More specific information on the subject is also presented in the *Update of Emission Estimate Methodology for Maritime Navigation* report [lx].

Based on the guidelines, CO_2, NOx and SO_2 emissions related to disposing of Frigg TCP2 on land are presented in table 4.

Table 4: Summation of emissions to the air from disposal of Frigg TCP2 to land.

Operation		CO_2 tonnes	NO_x tonnes	SO_2 tonnes
Marine operations	Mobilisation and demobilisation	5 000	90	19
	Refloating	14 000	270	54
	Transport to near receiving facility or to quay	13 000	240	48
	Landing operations	5 000	110	21
Demolition			113	0,3
Recycling of rebars			26	63
Total emissions to the air			750	205

6. Conclusion

The environmental impact of abandoning concrete installations in the North Sea is limited. The biological production which currently occurs on these installations would disappear if they were removed, and the structures do not affect fish populations or fishing.

If they are fitted with lights and navigation equipment, the threat of any conflict with shipping is small. Were the installations also cut down to 55 metres beneath sea level, they would present no restrictions to shipping at all.

At the same time, the potential environmental impact of removal to land is substantial. A danger of accidents naturally exists when refloating installations and moving them to land, but the conflicts primarily relate to environmentally acceptable environmental reconstruction, demolition and intermediate waste storage. These operations are expected to involve a high risk of dispersing polluted water as well as much dust and noise.

A large amount of space would be required, both on land and in the sea, and the level of potential conflicts with neighbours is expected to be high.

In terms of energy consumption and emissions to the air, abandonment of a concrete structure at sea would be far more favourable than disposing of it on land.

From an overall perspective, therefore, offshore abandonment would clearly have the lowest environmental impact.

A collective overview of the potential environmental impact of the two alternatives is presented in table 5.

Table 5: Overview of the potential environmental impact of abandoning concrete installations or of finally disposing of them on land.

Activity	Potential pollution sources	Environmental impact	Concerns	Positive elements
Abandonment offshore	Whole concrete installation	Potential leaking of pollutants to the water column and sediments, which can affect habitats over a long period	Physical presence of the structure on the seabed No opportunity to recycle steel or concrete from the installation Actual quantities and concentrations of environmental toxins in the structure Potential risk related to navigation and commercial fishing	Lower energy use and emissions than refloating, transport and breaking up No disruption of biological diversity on and around the concrete installation
Refloating	Energy use and emissions from vessels, equipment and cranes Loss of equipment/ballast, etc	Pollution from discharges/emissions	Leaking of pollutants to the water column and sediments, which can affect habitats for marine flora and fauna	Original natural condition re-established over time
		Direct impact on marine life and indirect impact related to disturbance of polluting sediments	Reduction in biological diversity	
Transport	Energy use and emissions	Local reduction of air and water quality	Accidents with/damage to the installation from transport	None
	Accidents with/damage to vessels or installation	Discharge of environmental toxins	Obstructions/residues on the seabed Loss of the installation	
Landing	Energy use and emissions	Local reduction of air and water quality	Restrictions on movement	None
	Use of explosives and/or mechanical cutting	Disruption of the local environment from noise and dust	Leaking of pollutants to the water column and sediments, which can affect habitats for flora and fauna with associated food chains	
	Sediment disturbance during refloating and positioning on the seabed off the receiving facility/quay	Mobilisation of sediments with associated increased turbidity in the water column	Residues on the seabed after landing activities	
Breaking up and disposal on land	Physical	Visual effects, disruption of local environment from noise and dust	General disruption of local environment. Physical presence and large area occupied	Supply of concrete and rebars which can be reused or recycled
	Energy use and emissions from cranes, crushing plant, vehicles, etc	Substantial emissions from crushing concrete compared with extraction from conventional quarry	Local/regional reduction in air quality	
	Removal and treatment of marine growth	Odour. Discharge of surplus water containing particles. Noise	Polluted coating/concrete, with environmentally hazardous substances in the growth	
	Demolition processes	Leaks of undesirable pollutants (heavy metals/oil) to surface, soil and seawater, which can affect food chains	Fine particles and dust may contain nitrogen. Run-off increases suspended particles in the water and creates problems for fish/other organisms	

		Emissions, dust formation. Noise from the facility. Eutrophication and increased sedimentation from dust particles	Working environment and health effects for employees and the local community	
	All waste delivered for recycling/intermediate storage, i.e, run-off for areas, etc, at the facility	Leaks of polluted spoil (demolished concrete), which could affect surface or ground water	Large volume of demolished concrete which cannot be reused or utilised as infill	
	Transport of waste on site and to approved reception plant	Danger of accidents when transporting substances hazardous to health and the environment internally or to approved reception plant	Leaks from vehicles or vessels carrying hazardous waste/pollutants in connection with transport	
	No approved reception plants, landfills or infill sites	Spreading pollution	”Fly-tipping”	

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