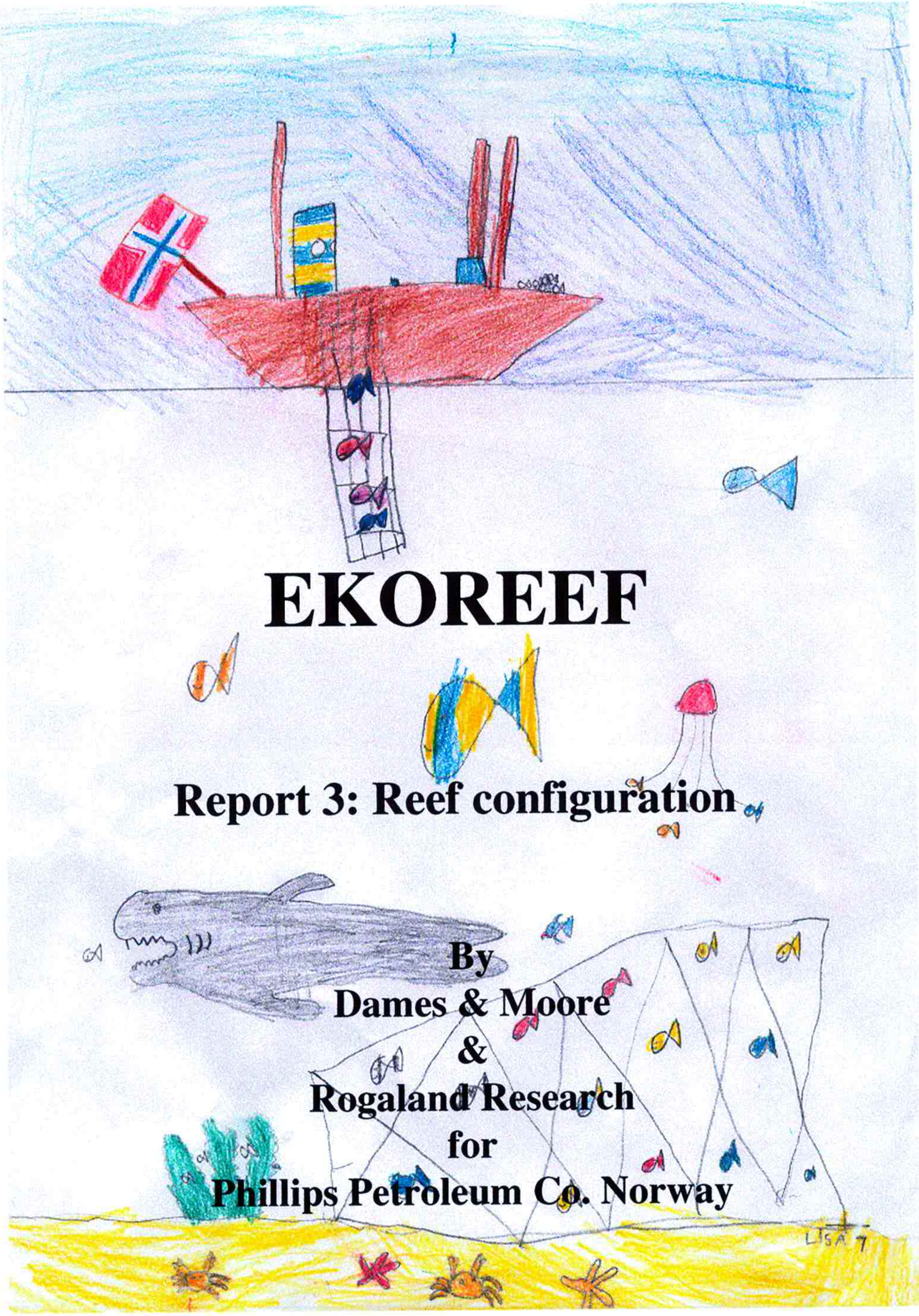

EKOREEF

Report 3: Reef configuration

By
Dames & Moore
&
Rogaland Research
for
Phillips Petroleum Co. Norway

EKOREEF - Report 3: Reef configuration

Report D&M 37363.001/2 - RF-98/008

Our reference:	Author(s):	Version No. / date:
DM37363.001/2 RF/771/654463.2	**Hovda, J.[2], Jacobsen, T.G.[1], Aabel, J.P.[2] and Cripps, S.J.[1]**	**Vers. 2 / 20-10-98**
No. of pages:	Project Quality Assurance.	Distribution restriction:
104	**Jacobsen, T.G.**	**Open**
ISBN:	Client(s):	Open from (date):
82-7220-941-1	**Licence PL018 through Phillips Petroleum Company Norway**	**1-1-2003**
Research Program:	Project title:	
EKOREEF	**Report 3: Reef configuration**	

Scope:
The four main aims of this study were to: define the locations of potential artificial reefs; identify and rank the usefulness of structures to be used as artificial reef components; design artificial reefs according to whether the reef is to be used for enhanced fishing or habitat protection; present alternative scenarios for reef creation at the Greater Ekofisk field.

The findings of this report are summarised and simplified in a main summary report for the Ekoreef programme.

Key-words:
Ekofisk, artificial reef, fisheries, environment, rigs to reefs, GIS, decommissioning, Ekoreef, offshore platforms.

Project Manager - Dames & Moore
Jens Petter Aabel

Project Manager - Rogaland Research
Dr. Simon J. Cripps

2 DAMES & MOORE
A DAMES & MOORE GROUP COMPANY

1 RF ROGALAND RESEARCH

CONTENTS

PREFACE

As the oldest exploited oil field in the North Sea, the Ekofisk field is currently approaching the end of production. Various options are being considered by the operators as part of a choice of field cessation plans required by the Norwegian government. One such option is the use of suitable, prepared, planned and located platform components as artificial fish attracting reefs: the "Ekoreef" option.

This report presents the findings of the second project (Report 3) within the Ekoreef programme. A total of 5 main projects have been conducted, and will together assist in the planning and estimation of the potential for one or several complex artificial reefs in the Ekofisk area.

The following reports have been delivered through the Ekoreef Programme:

1. *Summary report* - The main points of the 5 projects have been collated into a concise summarising document.
2. *Present status* - Recommendations have been given as to which areas around both the Ekofisk Tank and the Greater Ekofisk field, appear most suitable for the construction of one or several artificial reefs. An overview of the decommissioned structures available and the general environmental situation, including fishing activities is presented.
3. *Configuration* - Optimal design or designs of a potential Ekoreef have been prepared. These incorporate recommendations for structures to be included in the reef, their configuration, location and the rationale used.
4. *Impacts* - Likely negative and positive impacts on the environment and associated socio-economics have been predicted. A waste management plan is proposed.
5. *Management* - A plan for the management of the Ekoreef, including an assessment of its most beneficial uses, has been prepared.
6. *Monitoring* - A plan for the future monitoring required around the Ekoreef is proposed.

GLOSSARY

Main structures:

1/6A & 2/4F	Albuskjell
2/4B & 2/4K	Ekofisk B and K
2/4D	West Ekofisk
2/4E	Tor
2/4H	Ekofisk hotel
2/4T	Ekofisk tank
2/7B, 2/7A & 2/7FTP	Eldfisk
2/7C	Edda
2/7D	Embla
7/11A	Cod

Terminology and acronyms

Benthic	Pertaining to the sea floor.
Demersal	Living at or near the bottom of the sea.
EARRN	European Artificial Reef Research Network
GIS	Geographical Information System.
MSF	Module support frame.
Pelagic	Pertaining to the water column.
Reference point	Fixed position of a platform which is not to be moved, about which the rest of the reef will be located.
THC	Total hydrocarbons
Ekofisk Centre	All platforms around the Tank, including Ekofisk A,B and K.
Economic lifetime	Time to end of production, i.e. to the closing down date.
Expected lifetime	Time to deterioration and collapse of structures.
Juxta-position	Position and orientation of structures as reef component in relation to other components.
Artificial reef core	Location of the central reference point for a reef.
Artificial reef unit	Reef comprising three or more components in close proximity.
Vortex shedding	Scouring, i.e. erosion, digging under a structure by ocean currents.
CVBS	Controlled Variable Buoyancy System
SSCV	Semi Submersible Crane Vessel

Fish species

Cod	*Gadus morhua*
Eel	*Anguilla anguilla*
Flounder	*Platichthyes flesus*
Haddock	*Melanogrammus aeglefinus*
Herring	*Clupea harengus*
Sole	*Solea solea*
Mackerel	*Scomber scombrus*
Plaice	*Pleuronectes platessa*
Saithe	*Pollachius virens*
Sand-eels	*Ammodytes* spp.
Whiting	*Trisopterus luscus*

3 EKOREEF REPORT 3: REEF CONFIGURATION

3.1 Summary

The configuration of several reef options at the Greater Ekofisk field are proposed.

The four main aims of this study were to: define the locations of potential artificial reefs; identify and rank the usefulness of structures to be used as artificial reef components; design artificial reefs; present alternative scenarios for reef creation at the Greater Ekofisk field.

To reduce the complexity of this multi-component task, several assumptions and limitations were made. The main points were: the tank will serve as an artificial reef site, from the time of its abandonment; the economic lifetime for the platforms are divided in two groups, those planned to be decommissioned in 1998-2005, and those decommissioned after 2005; no economic evaluations of the reef configurations were considered; only jacket-structures are used as reef components, not topside modules, as will be explained. This study was divided into four main parts:

- identification of suitable locations for the artificial reefs;
- identification of potential reef component structures;
- design of the artificial reefs;
- scenarios for establishing one or several Ekoreefs.

Each of these 4 parts were then divided into: introduction, identification, criteria, and evaluation.

Reef locations

The following parameters were used to determine potential reef locations: oceanographic parameters; prevalence of fish; drill cuttings disposal options; location of pipelines; contamination concentration and distribution; and platform location. The Ekofisk Tank, Albuskjell 1/6-A, and Eldfisk 2/4-B were chosen as potential reef sites. *In situ* toppling was discussed as a potential option.

Reef structures

Existing facilities and their economic lifetime were identified, together with considerations such as: interaction with operating platforms and risk of decommissioning activity; stability of structures; transport of jackets vs. toppling in place. Criteria for structures were: volume and structural complexity of jacket; toppling in-place, or transport of jacket; and economic lifetime of the jackets. The jackets were evaluated and ranked, focusing on the usefulness of each structure at either the Ekofisk Tank, Albuskjell 1/6 A or Eldfisk 2/7-B sites.

Design of artificial reefs

Reef designs for the purposes of this study were identified as either a straight line, a block formation, in a circular pattern, or inserted within each other. Reef design criteria differed from criteria used to determine suitable locations and structures. Orientation, i.e. compass direction; juxta-position of jackets within a reef; number of jackets at the reef; and distance

between jackets in the reef were used as design criteria. Reefs were designed for fish stock protection and for enhanced fishing.

Ekoreef establishment scenarios

The following four main alternatives scenarios were defined:

Alternative 1 (Centre): A single complex reef will be created around the Ekofisk Tank using structures as they become available, until all of the platforms are decommissioned after 2028.

Alternative 2 (Tank, Eldfisk): A reef will be created north-west of the Ekofisk Tank using platforms decommissioned before 2005. A second reef will be created at Eldfisk 2/7-B using platforms decommissioned after 2005.

Alternative 3 (Centre, Tank): A reef will be created at Ekofisk B/K containing structures that will be decommissioned before 2005. The reef will be expanded at the Ekofisk Tank and a second reef complex created with platforms decommissioned after 2005.

Alternative 4 (Albuskjell, Eldfisk): A reef will be created at Albuskjell 1/6-A using platforms decommissioned before 2005. A second reef will be created at Eldfisk 2/7-B using platforms decommissioned after 2005.

Alternative 5 (Albuskjell, Tank): A reef will be created at Albuskjell 1/6-A using platforms decommissioned before 2005. The reef will be created at the Ekofisk Tank and a second reef complex created with platforms decommissioned after 2005.

Alternative 6 (In situ toppling): All platforms at the Greater Ekofisk Field will be toppled in-place as they become decommissioned.

A total of 11 alternatives are visualised and presented as potential scenarios. Within each of the first 10 Alternatives, both a habitat protection (p) and an enhanced fishing design (f) are presented.

The GIS based presentation of each scenario contains information such as:

- production fields around the platforms;
- location of pipelines, both export and production pipelines;
- total hydrocarbon (THC) contamination concentration and distribution;
- location of each platform structure placed in a reef unit;
- volume of each structure, indicated by use of colour codes;
- use for habitat protection or enhanced fishing.

Conclusions and recommendations

The Ekofisk Tank is suggested as an artificial reef site assuming it is to be abandoned. It is sited in a convenient location, i.e. several platforms may be toppled in-place at this site. It is expected that the current unsuitable contamination concentration and distribution in the sediments of the region may change for the better in the future because of cleaner production techniques and reduced oil industry activity.

The Albuskjell 1/6-A and Eldfisk 2/7-B are suggested as artificial reef sites because of the absence of pipelines, the low contamination concentration and its limited distribution. The location is also convenient in relation to other platforms in the proximity.

In situ toppling is suggested as a potential alternative primarily because the cost of reef implementation would be relatively low. The resulting reef configuration would be more suitable for habitat protection than for enhanced fishing. Reef design flexibility and avoidance of contaminated sites is though limited to some extent.

A detailed evaluation of all structures to use at the three potential reef sites at Ekofisk Tank, Albuskjell 1/6-A and Eldfisk 2/7-B indicates that some structures are more suitable than others, depending on which Alternative is decided upon.

The design of a reef is dependant on its purpose. Reefs laid out in a straight line should assist fishing. Those assembled in blocks or circular patterns are suitable for fish stock protection. Insertion of structures within each other can increase the structural complexity of a reef.

Though a cost analysis was not within the remit of this study, from a solely financial aspect, the most favourable Alternative appears to be 6, i.e. *in-situ* toppling. Alternative 1, creating reefs as they become available until all of the platforms are decommissioned, also appears an economically favourable scenario.

From an environmental (contamination) perspective, the most favourable Alternative appears to be 4, i.e. the Albuskjell 1/6-A reef site, with all structures decommissioned in 1998-2005, and another reef site at Eldfisk 2/7-B with all structures decommissioned after 2005. As no reef will be created around the Ekofisk Tank, transportation of several structures would though be required.

3.2 Introduction

3.2.1 Background and aims

Any structure that, deliberately or not, provides the effect of a natural reef, may be denoted an artificial reef. Marine artificial reefs have been defined in 1996 by the European Artificial Reef Research Network (EARRN) as: submerged structures deliberately placed on the seabed to mimic some characteristics of a natural reef. Reef creation should therefore not be confused with offshore dumping, which is a very different proposed decommissioning option involving disposal without planned proposed benefits.

Aims for Report **3** are as follows:

1. define where artificial reef(s) may be **located** on the greater Ekofisk field;
2. identify and rank **structures** to be used as artificial reef components;
3. propose artificial reef(s) **designs**;
4. present different implementation **scenarios** for the Greater Ekofisk field.

The evaluation of each location, structure or design is based on a defined set of criteria, with the environmental and fisheries issues prioritised. Figure **3**.1 summarises the logical structure of the decision making process in this report. The following steps are conducted.

1. Locations. Suitable locations are described in detail. Unsuitable locations are described, and the reasons for their lack of suitability are justified.
2. Structures. Identification and criteria for choosing suitable structures to use at the Ekofisk Tank and other potential reef sites are presented. Suitable structures to use at the three different locations are evaluated.
3. Designs. Identification of designs, and criteria for choosing suitable designs are presented. The evaluation section will examine two perspectives: the proposed use of the reef for either habitat protection or fishing enhancement. These issues will be discussed and serve as guidelines for the presentation of the different scenarios.
4. Scenarios. Plan for the establishment of platform reefs, incorporating locations, structures, designs, usage and a time perspective.

To avoid a potentially complex scenario discussion, this report will suggest the use of the Ekofisk Tank as one of the artificial reef sites, and additionally two other potential reef sites.

The reef configuration described in this chapter will be based on several assumptions and limitations.

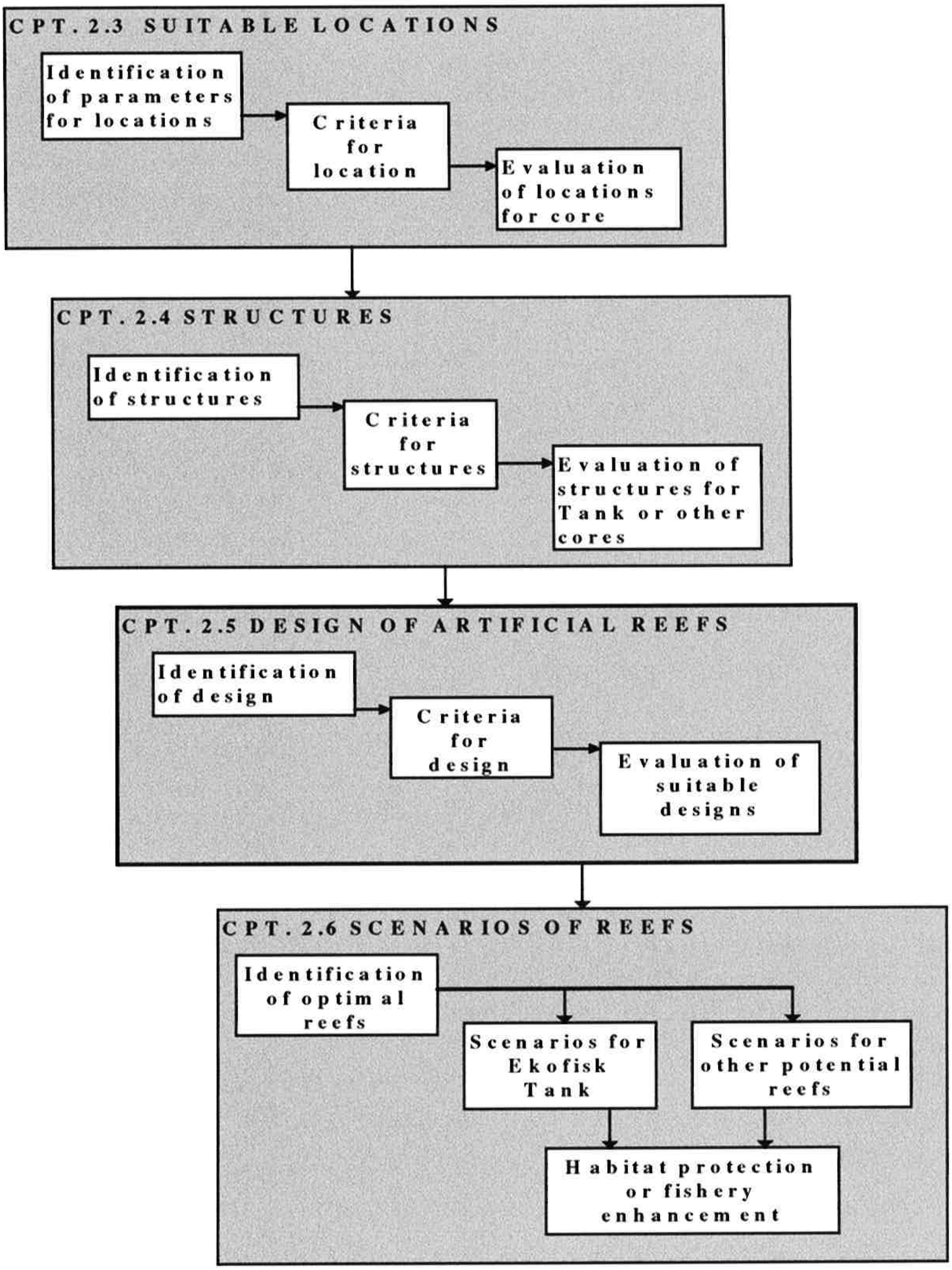

Figure 3.1: *Logical structure of Report 3: Reef Configuration.*

3.2.2 Assumptions and limitation

Based on Figure 3.1 assumptions and limitation can be described. There are several reef creation and implementation options. Again, this report focuses mainly on the environmental and fishery issues, therefore the assumptions and limitations are determined with these receiving the highest priority.

The assumptions are as follows.

1. It has been assumed that reef creation will be considered a new use of the existing structures rather than the installations being considered subject to regulations of "disposal" as defined in the London Dumping Convention and the IMO guidelines (see *Report* 4, *Impacts*).
2. The Ekofisk area has been proposed as one of four suitable areas for creating artificial reefs in the Norwegian sector of the North Sea (Aabel *et al.* 1997). The following criteria were used to support this assertion. The area must hold a large number of steel jackets, thus reducing transport costs. The area should hold one or more concrete installations that could act as a reef centre. The area should not interfere with known spawning grounds for fish stocks.
3. Some platforms could be toppled in place, with additional jacket structures placed in close proximity. Only jacket legs are considered, the use of topside modules are outside this scope of work. The module support frame (MSF) between the topside modules and the steel jacket is more akin in construction and materials to the frame of the jacket leg, and it is debatable whether the frame should be treated as part of the topsides or part of the jacket, for the purpose of this study, it has been regarded as part of the topsides.
4. Some platforms, that are suitable components for an artificial reef, are located close to the Ekofisk area, but are outside the Norwegian sector. Only platforms within the Greater Ekofisk field in the Norwegian sector of the North Sea are considered in this report. Platforms Ekofisk 2/4S and 2/4G are owned by Statoil and Amoco, respectively, but will be included in this report as potential reef components.
5. Some of the structures are already acting as fish attracting devices (see *Report* 2, *ROV Study*), but this has little influence on the choice of location or structures chosen. All the jackets are assumed to have the same ability to attract fish. The protection and habitat considerations for artificial reef creations are other perspectives, and will also be discussed in this chapter.
6. Steel elements such as flare stacks, bridge supports and bridges are included in this study although they may not be suitable as elements in artificial reefs. The total volume of an artificial reef will however make these components insignificant.
7. Ekofisk Tank 2/4 T is abandoned and left standing in place. The deck structures and top-side modules will be removed, and remaining structures will be stripped of all contaminants. Ekofisk Tank may be used as the centre of the site to which several jacket structures will be either toppled in place or transported to the Tank to optimise the reef configuration. All structures around the Tank including Ekofisk A, B and K are included in the evaluation of the location as a suitable reef site.
8. From an artificial reef aspect, the effect of a standing concrete structure will be less than a steel lattice structure. This results from a lack of structural complexity and usable volume.

9. Many of the jacket structures may be moved to a new location, the total cost of these operations is outside the scope of this study and as such has not been evaluated. The optimisation of a reef configuration and avoidance of the most contaminated sites will have to be weighted against the economical considerations.

10. Clean steel, the remains of the anodes and protective paint from the splash zone will be the only materials present on the seabed. No other materials or chemicals that will pose a short or a long-term contamination or pollution threat will be present.

11. The clustered reef options will give fewer, but larger enclosed volume reefs compared with *in-situ* toppling of all the structures. Creation of clustered reefs will, in the long-term, be of less hindrance to the fishing industry because the total area covered by reefs and their surroundings will be less and more defined.

12. The implementation of artificial reef creation depends on the economic lifetime of the different platforms. There are two options as a result of this: either delayed or immediate clustered reef creation. One advantage of immediate reef creation is that a reef community has the opportunity to develop at the artificial reef sites without any fishing pressure, because the sites will be protected from fishing by existing safety zones around working platforms. The success of the reef can also be monitored prior to large-scale reef implementation. A combination of both alternatives will probably be used to optimise the reef configuration.

13. Anodes are left on the jackets when used as reef component. This should greatly increase the lifetime of the artificial reef components.

14. Horizontal vs. vertical component. Optimal reef design may be achieved by maximising the horizontal component rather than the vertical (Grove *et al.*, 1989). This is supported by results of the video survey described in Report 2, *Current Status*. Structures will be either toppled in place or transported to a new location. Most of the structures are though not square in cross-section, but are rectangular. There is then the potential to maximise either the horizontal or vertical component at reef creation. In this report the structures will be toppled or placed so that the horizontal component (i.e. low reef side) will be maximised. This will increase the clear water depth, thus reducing the possibly of future hindrance to shipping. The area (m^2) of covered seabed will be maximised, so providing a greater habitat area for benthic and demersal fish communities. The stability of the structures will also be expected to be increased.

15. In terms of the economic lifetime of the different platforms at the greater Ekofisk Field, the platforms are divided in two. Those that will be decommissioned in the period 1998 - 2005, and those that will be decommissioned after that 2005. The production and economic lifetime of each platform is continuously assessed during operation. A two stage decommissioning strategy allows a greater flexibility in planning and makes the whole project less complex. A reef may be constructed, even if the availability of some components is delayed for operational reasons.

3.3 Potential reef locations

3.3.1 Introduction

Firstly, important considerations and parameters for choosing locations are identified. The criteria for choosing suitable locations are the presented, followed by a discussion on the different locations for artificial reef sites. Suitable locations for artificial reef sites are then defined and evaluated. Unsuitable locations are briefly described, with the reasoning behind their lack of suitability.

Two main assumptions are used to simplify planning of the reef configuration:

- Ekofisk Tank will serve as an artificial reef site, since it will be abandoned;
- the economic lifetime for the platforms are divided in two groups, those that are planned to be decommissioned in the period 1998 - 2005, and those that will be decommissioned after 2005.

3.3.2 Identification of location determining parameters

3.3.2.1 Contamination characteristics

In order to create clustered artificial reefs most of the platforms will have to be moved away from their original sites. During the toppling and removal of the structure, some of the cuttings pile may be re-suspended. No data is available to estimate the quantity of material re-suspended during structure removal, compared with the total retrieval of the pile. Oily cuttings pile removal may then be beneficial if the site is to be used for a reef.

Some sediments in the vicinity to some production platforms have been shown to contain high concentrations of heavy metals because of leaching, mainly from cuttings piles. Some of the heavy metals, especially mercury and cadmium, tend to bond to particles and end up in the sediment. Heavy metals are not degradable and will therefore remain in the sediments unless they are re-suspended. Close to some platform these concentrations are elevated compared with the background levels in the North Sea. The impact this would have on the communities using an artificial reef is not known.

Concern has been expressed, however, about the potential effects of high concentrations of lead, cadmium and mercury in relation to top predators such as seals and certain seabirds. With the exception of flounder (*Platichthyes flesus*) and eel (*Anguilla anguilla*) in the Elbe and its estuaries (which are not allowed to be sold because of their high mercury content), none of the concentrations of metals found in the commercially exploited fish or shellfish in any area of the North Sea exceed standards set to protect human health (North Sea Task Force, 1993).

Thus, while there continue to be good reasons for exercising control over heavy metal inputs in general, if present controls and decreases in inputs are maintained, the desired improvements should be achieved in most areas. Points that remain to be clarified are the biological significance of the highest concentrations in both total and fine fractions of sediments and the speed of recovery in areas of short to medium term deposition (North Sea Task Force, 1993).

No recent estimates has been produced of the magnitude of oil inputs from all sources to the North Sea. Nevertheless it has been estimated that up to 2 % of the seabed of the total North

Sea has been affected by oily drill cuttings, i.e., oil is detectable in sediments and/or there have been changes in the species present.

Monitoring of the piles of contaminated cuttings around some of the worst affected platforms shows effects on zoo-benthos (bottom living animals) within 0.5 to 1 km of the platform. Occasionally, there are detectable effects up to 5 km from the installation (see report 2, *Current status*). At a number of platforms, once drilling has ceased the area in which biological effects or oil contamination are detectable decreases. Macro-benthos recovery in the moderately affected zones usually takes place within two to three years (North Sea Task Force, 1993).

Fish exposed to hydrocarbons could possibly become tainted. The International Standards Organisation and British Standards Institute definition of taint is, "a flavour or odour foreign to the product". It appears that only demersal fish actually in contact with disturbed cuttings piles are likely to acquire a tissue burden of hydrocarbons and a taint. The potential for tainting from an extant mound would therefore be limited to an area <200 m from the point of cuttings discharges.

Mid-water pelagic fish frequenting the area of freshly exposed cuttings may acquire an elevated tissue hydrocarbon burden, but there is no evidence to suggest that this would lead to any detectable change in flavour. Fish with increased hydrocarbons and with a taint are likely to degrade hydrocarbons within weeks or months of moving away from the source of hydrocarbons (Picken, 1995).

3.3.2.2 Oceanographic parameters

Bottom topography is important in relation to circulation and vertical mixing. Flow tends to be concentrated in areas characterised by the steepest slopes, with currents flowing along the depth contours. Prevailing surface sediment types at Ekofisk are fine to medium sands, also coarse sand and gravel sand may be found locally. The fine material indicates a low dynamic energy movement.

The overall depth in the Ekofisk field is about 80 m. Around the jackets, up to 15,000 m^3 of drill cuttings are deposited. These deposits contain material of all grades from coarse to fine, and older piles (pre 1989) are generally contaminated with oil. These piles should therefore preferably not be re-suspended.

3.3.2.3 Possible flow and scour features

Tidal flow is relatively weak, with a range in the order of 1 m. The combined effect of storm, wind and tide will generate a surface flow of about 0.8 m/s (Olbjørn, 1974). Wave-induced flow will be weak on a daily basis, but can be significant in storm situations. Wave heights of 5, 10, 20 and 27 m (the 100 year wave) occur in the area, and can have an influence on the bottom flow velocity.

3.3.2.4 Flows through a platform reef

The 90 m diameter concrete Ekofisk tank is surrounded by steel jacket platforms. Their size and shape varies, but they typically have a 40 by 90 m footprint arranged as two rows of legs with 4-5 legs in each row. The jacket legs are circular cylinders with a diameter of about 2 m or less. In addition, there are multiple smaller-diameter stays connecting the legs.

Either upright or toppled, the flow through the jackets consists of a complex pattern of wakes with wake-structure and wake-wake interactions. This is so in a steady flow. During oscillatory wave flow the picture is even more complex, with the wakes being advected back and forth over the structure. A detailed description of the flow neither feasible nor desirable for this study. An introduction to the subject is though presented in three sections:

- flow over a jacket leg, above the sea-bed,
- flow over a jacket leg, at the sea-bed,
- vertical flow at a vertical jacket leg

(1) Flow over a jacket leg, above the sea-bed

When a jacket leg (cylinder) is in the vicinity of the sea bed (wall), the vortex shedding is influenced by the presence of the sea bed (wall). This has been studied by Bearman and Zdravkovich (1978) and others. Mao (1986) investigated the scour caused by vortex shedding from pipelines place above a sea-bed. The experiment showed that scouring would appear downstream of the pipeline if the gap was less than about 2 pipeline diameters.

Numerical simulations by Brørs (1997) for a pipe with a 0.6 d gap indicated that the vortex shedding produced fluctuating bed-stress from the pipe about 7-8 d down-stream, with the largest variability at a distance of about 3.5 d. At this point the fluctuation in the friction velocity was about 40 % of the mean value.

(2) Flow over a jacket leg, at the sea-bed

A steady flow crossing a jacket leg at the sea-bed will separate at, or slightly behind the top of the jacket leg, and reattach to the sea-bed 8-10 diameters down-stream of the jacket leg. Along this stretch, a re-circulation zone with height about 1.6 d will form. The thickness of the inflow will have some influence on the local flow-characteristics. Flow at surface mounted cylinders (jacket leg at the sea-bed) has been studied in detail by Solberg (1992).

It is well known that scouring can develop at pipelines and cylinders (jacket legs) at the seabed in general, when the flow is allowed to penetrate underneath. In one-directional flow, a scour hole will develop with a maximum depth directly underneath the cylinder and with deposits forming a ridge along the down-stream side.

(3) Vertical flow at a vertical jacket leg

A jacket leg placed as a reef in a vertical position will be influenced by periodic vortex shedding with high Reynolds number. Near the sea-bed the vortex shedding (i.e. scouring) is damped by the sea-bed boundary layer. Here, a different phenomenon called the horseshoe vortex dominates. It is formed by the downward flow impinging at the seabed in front of the cylinder and being advected along both sides of it into the lee wake. The phenomenon and associated local scour is reviewed by Breuser *et al.* (1977) and Niedora & Dalton (1982). Data seem to indicate that the scour hole depth at cylinders is less than 2 d. There is evidence that for a large group of piles, there will be a general depression in addition to the local scour holes at each pile.

(4) Flow at a rough portion on a plane seabed

As a first approximation, an artificial reef can be modelled as a rough patch on an otherwise relatively smooth seabed. According to Schlichting (1979, pp657-658), the wall (bed) shear stress will immediately adapt a new and increased value where the flow reaches an area with increased roughness. A new linear shear stress profile, with the new and larger wall value, will develop in the downstream direction.

This situation has been simulated with the geophysical flow model GEOSIM. It is a one-equation, quasi three-dimensional geophysical flow model, comparable to the one described in Utnes and Brørs (1993). It solves an equation for the turbulent kinetic energy k, and the eddy-viscosity Av is set equal to:

$$Av = C(1/4\ k1/2\ 1\ )$$

where C(= 0.09 and l is an algebraic expression for the turbulent length scale).

A 1000 m wide, 1500 m long and 80 m deep domain has been modelled. This can be assumed is the area of importance to consider if an artificial reef unit, containing jacket structures placed in desired juxta-positions. It extends from x = 0 to x = 1500 m in the flow direction and from y = - 500 m to y = 500 m normal to the flow.

A high bed roughness has been defined for the 300 by 500 m rectangular area extending from x = 300 m to x = 600 m and from y = -250 m to y = 250 m. by 500 m. Here, the roughness parameter is set equal to z0 = 0.2 m. This is a very high roughness, typical for "many trees, hedges, few buildings" in atmospheric flows (ESDU, 1974). Elsewhere, the roughness parameter is set to z0 = 0.0001 m, typical for a smooth seabed with fine sand with a grain diameter in the order of 0.001 m.

The flow is forced by specifying a water level of (= 0.005 m in x = 0 and (= 0 in x = 1500 m. This pressure gradient causes a flow with a surface speed in the order of 1.15 m/s. Figure 3.2 shows the predicted surface elevation and near-the-bed (z ~ 0.3 m) flow speed.

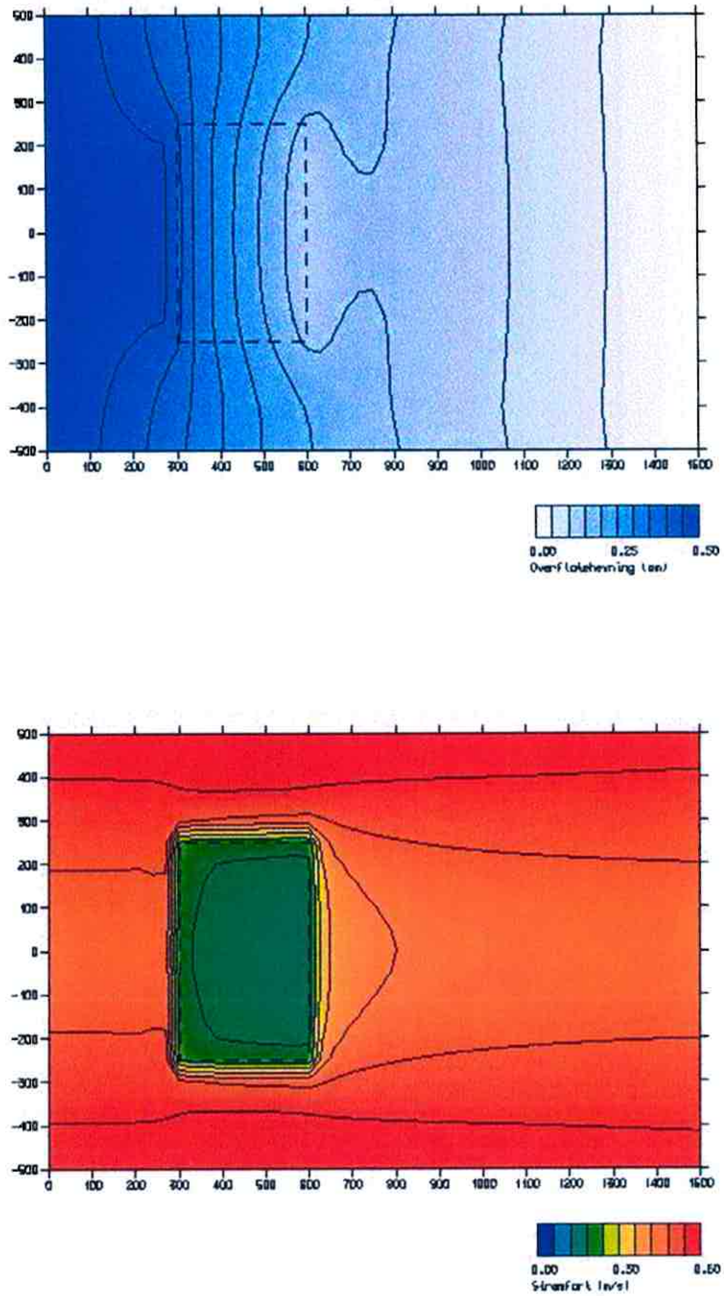

Figure 3.2: *Predicted surface elevation (upper plot) and near-the-bed flow speed (lower plot) generated by a rough area. The dashed line indicates the extent of the rough area.*

The rough area has a large impact on the shape of the free surface. In a constant roughness case, the water level would decrease uniformly from left to right with an even slope of 0.5 cm over the 1500 m length. Here, the slope of the free surface is 2-3 times as steep over the rough part. To the lee of the rough patch, the surface slope is less steep, and partially even in the opposite direction.

The lower plot shows the predicted flow speed in the near the bed level approximately 0.3 m above the seabed. The speed drops from a value of about 0.45 m/s in front of the rough area to about 0.16 m/s over the rough area, and assumes its original value relatively quickly down-stream of it.

Flow profiles have been extracted from the simulation. The profiles are taken along the centreline y = 0, in the locations x = 150, 300, 450, 600, 900 and 1350 m. Figures 3.3 – 3.5 show vertical profiles of flow speed, turbulent kinetic energy k and eddy viscosity (turbulent diffusivity in the vertical direction), Av.

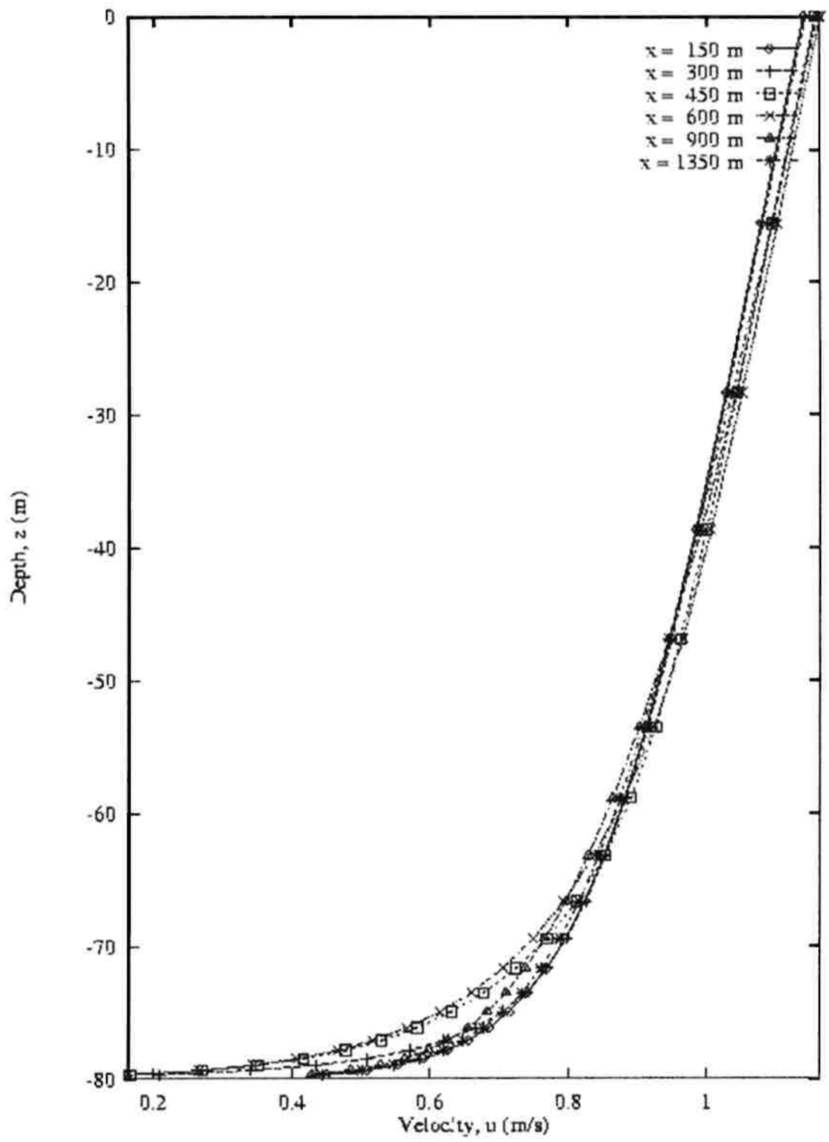

***Figure 3.3**: Predicted profiles of flow velocity u along y = 0.*

The near-the-bed flow is seen to react suddenly to the change in roughness in x = 300 m, by a speed decrease of more than 60 %. Only the lower few meters close to the seabed are affected, however. Further down-stream, in x = 450 m and x = 600 m, the wall speed stays constant but the slowing down of the flow occurs higher up in the water column. The effect is, however, confined to the lower 15 – 20 m or so. The surface flow speed is seen to undergo a speed decrease of about 2 % down-stream from the onset of the rough area in x = 300 m. This is consistent with the increase in the surface slope.

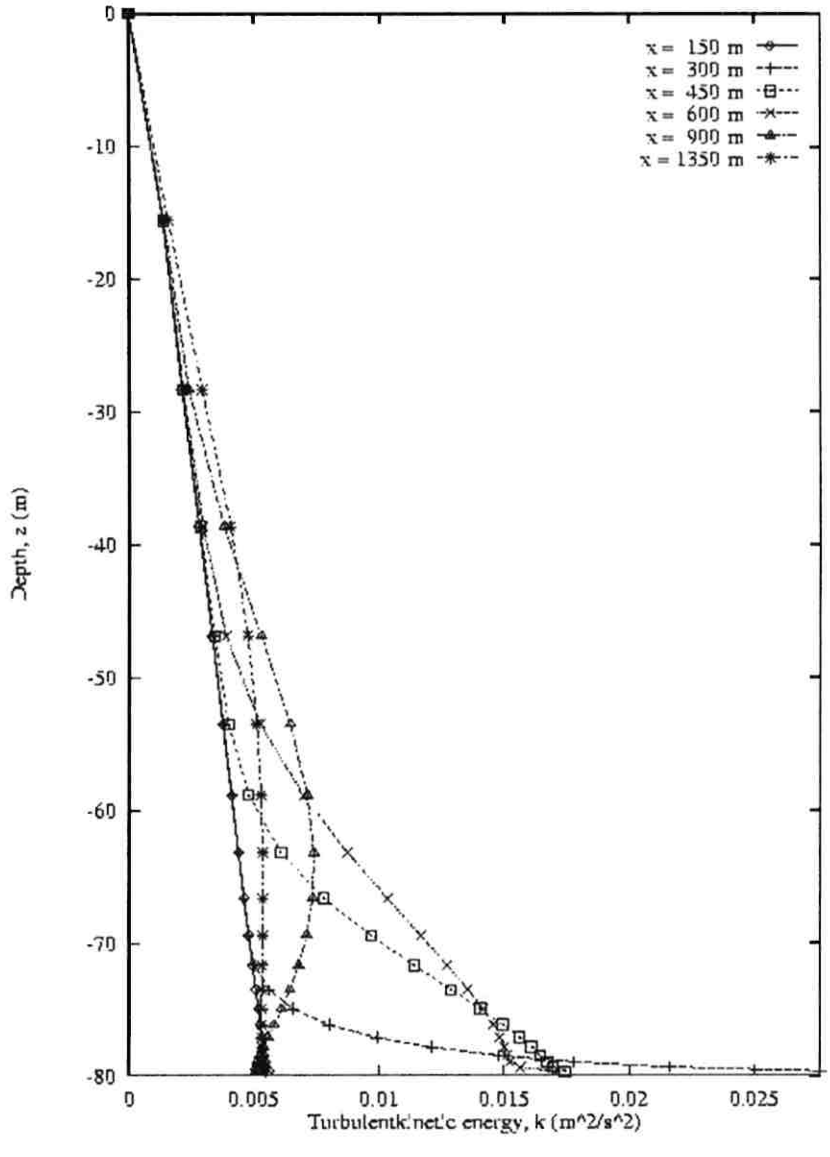

***Figure 3.4:** Predicted profiles of turbulent kinetic energy k along y = 0.*

The turbulent kinetic energy profiles are shown in Figure 3.4. In front of the rough patch, k decreases almost linearly from a value of about 0.005 m^2/s^2 to nil at the surface. Scaled with the bulk free-stream flow speed of about 1 m/s, this means that the turbulent fluctuations are roughly (0.005/1)1/2 ~ 0.07 times the mean flow speed. Turbulence levels increase to over 0.03 m2/s2 at the onset of higher roughness in x = 300 m. This corresponds to turbulent flow in the order of more than 0.17 times the free flow mean speed. Further down-stream, in x = 450 m and x = 600 m, the wall values of k decrease as the wall flow slows, and turbulence values are increased significantly 20-30 m from the seabed.

After the rough stretch, the wall value of k decreases quickly, and the additional turbulence generated along the rough area diffuses further up the water column. In x = 900 m, a maximum in k of about 1.7 times the normal value at this height is located 15 m above the seabed.

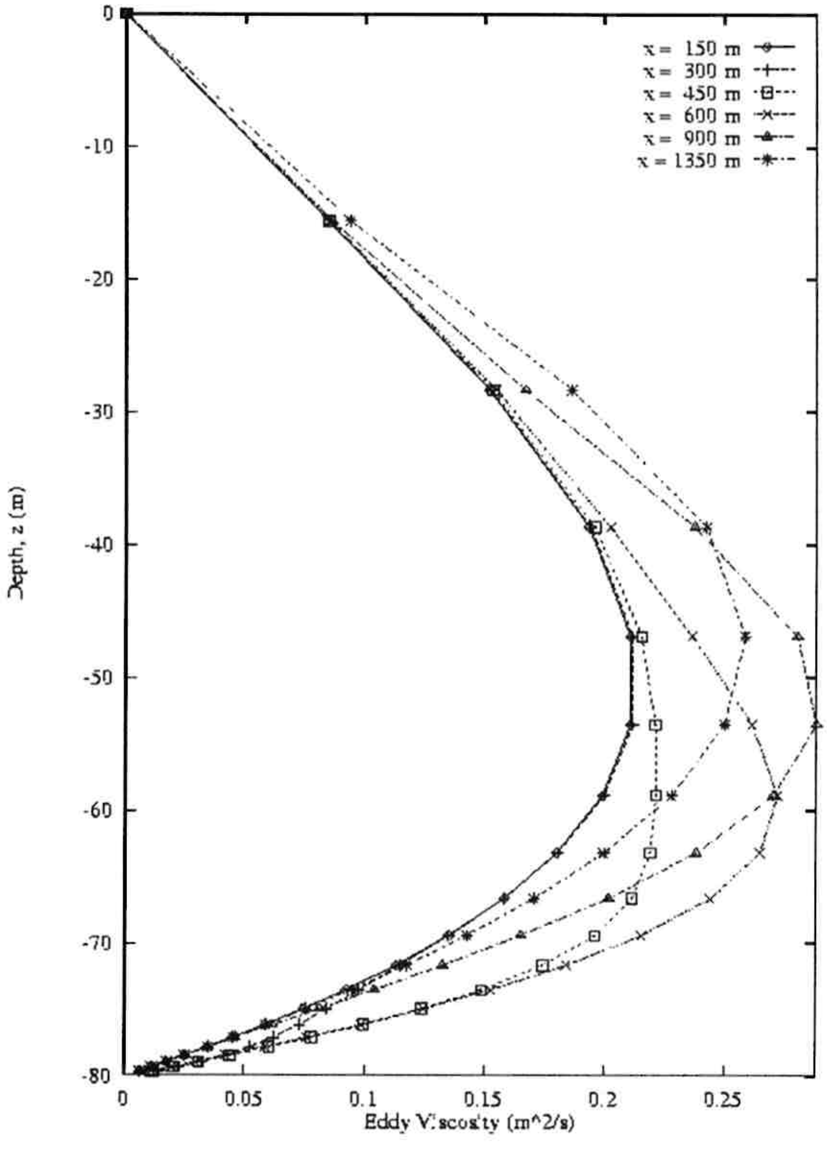

Figure 3.5: *Predicted profiles of vertical eddy viscosity A_v along y = 0*

The turbulent eddy viscosity profiles (for turbulent diffusion in the vertical direction) are shown in Figure 3.5. The rougher area is seen to increase the Av values significantly in most of the water column, with the effect moving upwards with increasing x after x = 300 m.

(5) Conclusions

Bottom topography is a flat sea-bed with average 80 m. The tidal flow is relatively weak. Sediment characteristics contain all grades from coarse to fine, and are generally contaminated with oil at production sites.

Local scour at a jacket leg at the sea-bed in a two-directional cross flow can be up to three jacket leg diameters (i.e. max 6 m). In a one-directional flow, it is likely to be less than one jacket leg diameter (i.e. 2 m or less).

Local scour at a vertical positioned jacket leg is likely to be less than two jacket leg diameters, i.e. less than 4 m.

Simulations show that near-the-bed flow adjusts to an increase in bed roughness immediately. The turbulence and velocity of the flow, gradually rises into the water column towards the sea-surface.

Generally, a jacket or several jackets on the sea-bed are influenced by the flow, some scouring will occur, but does not appear to have any negative effect on the stability on the reef itself.

3.3.2.5 Fish considerations

(1) *Spawning grounds*

The information presented in Report 2: *Current status*, indicates that the area that incorporates Ekofisk is part of a spawning ground for a very few species of pelagic fish such as mackerel (*Scomber scombrus*). Such fish are unlikely to be disturbed by the presence of an artificial reef on the sea floor, especially when the area covered by the reef is a very small fraction of the total spawning ground. Whilst the adults of such pelagic species may not be attracted for long to a reef, the juveniles have a different ecology and may well use a reef for feeding or protection.

(2) Conclusions

From Report 2: Present status, fish considerations are taken into account. Conclusions from this section are as follows:

- Fishing industry activity in the central North Sea area in the vicinity of the Ekofisk platforms is mainly focused towards sand-eels that are processed into fish meal.
- The region around Ekofisk is marginal fishing area for high-priced demersal fish, such as cod, saithe (*Pollachius virens*), haddock (*Melanogrammus aeglefinus*) and plaice (*Pleuronectes platessa*). The annual market value of these fish landed in Norway from this area is below 0.8 M NOK.
- The facts can be interpreted such that the current low adult stocks of demersal species in the Ekofisk area may benefit from the presence of platform reefs.
- The pelagic fishery is unlikely to be greatly enhanced.
- Some limited spawning of high value species such as cod (*Gadus morhua*) and mackerel does occur in the vicinity of Ekofisk, so there will be juveniles that may benefit from a protecting platform reef.

Also the results of ROV studies on the Greater Ekofisk field, conducted as part of Report 2, indicate the suitability of creating artificial reefs in the area. Conclusions from this study were as follows:

- Pelagic fish were generally not attracted to the Ekofisk structures during the survey.
- The survey was conducted at a time when few pelagic fish would be expected to be present.

- Large numbers of demersal fish, mainly cod and saithe, were observed at the majority of structures.
- High profile reefs would be expected to be of little extra benefit than low profile reefs with an extended base area.
- Larger complexes may have attracted more fish than smaller individual units.

Overall, a reef created at Greater Ekofisk field may potentially give positive results in terms of fishery enhancement. Once a reef is placed on the seabed, further investigation to yield hard data will be required to indicate if the fish populations in the area actually benefit.

3.3.2.6 Drill cuttings disposal options

Pulling the entire structure over, when toppling in place, will free the seabed area of the current jacket base. In the case of operations to clean the seabed for drill cuttings, this may be an advantage, because the former jacket base area will become more accessible. The contamination and drill cuttings piles considerations, and sea bed restoration for an area where a jacket is toppled in place and a area where the jacket are transported away, are analysed in the next section.

The Ekofisk field was the first in the Norwegian sector to be exploited. Production started as early as in 1971. At this time, there were no specific restrictions from the Norwegian Government concerning the disposal of drill cuttings. The muds that were being used were mainly based on oil or diesel, and the cuttings that were being produced were dumped directly into the sea. These drill cuttings created large piles, situated around and within the platform structure.

During the mid 1980's the increased concern for the marine environment resulted in banning of the oil-based muds. Today, drilling muds are mainly water-based. Cuttings are normally either cleaned and dumped in the sea, or they are re-injected. Oil-based cuttings piles on the sea-floor are a major source of hydrocarbon and heavy metal contamination. When considering an artificial reef site, it is of great importance that the reef is not influenced by the piles. In the following text, some of the options for drill cuttings disposal are discussed. These are based on Cripps et al. (1998).

(1) Leave the piles undisturbed

Some of the oldest piles on the seabed have developed a hard crust or they have been covered with cleaned water-based drill cuttings. This will reduce the leaching from the piles, locking away any potential environmental contamination. The oil content of the piles may decrease with time, at least in the upper layers, as a result of biodegradation by naturally occurring bacteria.

From previous investigations (Davies & Kingston, 1992; Daan & Mulder, 1995) of cuttings piles and the surrounding areas, the area outside the direct impact of the pile seems to restore totally within a few years after cessation. Little is known about the physical and chemical composition of the piles, and a thorough investigation of hydrocarbon leakage rates would need to be conducted for each pile if they are allowed to remain behind in a reef area.

In some cases, oil reducing bacteria have been known to produce methane and hydrogen sulphide gases. Both of these gases are poisonous, but they will probably escape the pile in very low doses and dilute very rapidly in the water column.

The environmental aspects of this option are quite positive. By leaving the pile undisturbed, there is little risk of resuspension, that might spread hydrocarbons to a larger area of the seabed and thereby pollute other areas. Resuspension as a result of the cutting and removal of a decommissioned platform, is though a significant but currently unquantified risk. It also poses a potential threat to the benthic community close to the pile. Another environmental aspect is the amount of exhaust and carbon dioxide which is produced by the machinery and the vessels which are needed to remove a cuttings piles.

Economically, this option is better than both retrieval and covering of the piles. Piles that are left undisturbed on the seabed may pose a threat to fishermen in the area, especially trawling vessels. Fishing equipment has the potential to resuspend parts of the pile, causing problems both to the environment and the fishermen. One option in this regard is to place platform jackets on top of the cutting piles as an artificial reef. By doing so, the piles will not be disturbed by fishing activities.

In the Ekofisk area, the drill cuttings have generally been discharged on the south side of the platforms. The highest concentrations of THC (total hydrocarbon) are however on the south-east side of the platforms as a result of east flowing currents in the area. If an artificial reef were to be placed near one of the platforms in the Ekofisk field and where the cuttings pile were to be left undisturbed, the best site would be on the north-west side. Any pollution from the cuttings pile should then be moved away from the reef site.

(2) Cover the pile for protection

There are at least three methods of covering a pile, and each has its advantages and disadvantages. Even though this method does not include removal of the drill cuttings pile from the seabed it can be expensive.

Entombment involves dredging seabed silos, removing and relocating the drill cuttings in the silos and covering the top. The seabed conditions would dictate whether this option is feasible. Compared to leaving the pile undisturbed, this is an expensive option. Apart from being expensive, it also has a negative impact on the environment. The dredging will destroy the benthic fauna in the area and the pile would probably be resuspended to some extent. Emissions to air during the operation would also need to be considered. Entombment, however, would not negatively impact fishing operations.

Capping can be achieved by means of an impermeable synthetic membrane attached to concrete mats. If the drill cuttings pile is obstructed by the platform jacket, the jacket would firstly have to be removed down to the level of the cuttings pile. The method is not expected to have any major effect on any areas other than those closest to the cuttings pile. Capping of the piles is expected to reduce the impact the piles have on fishermen.

Rock-dumping is an established technique in the offshore industry used for applications such as adding protective cladding to exposed or free-spanning pipelines or other structures. The method involves dumping material ranging from gravel to small boulders from surface vessels. If this method is to be used to cover a cuttings pile it is likely that the jacket structure will have to be removed down to the level of the pile. This method will probably have a negative environmental impact on the sediment, and there is no guarantee leaching will not occur. The method is not too expensive, but there may be some problems with trawling vessels snagging the rocks and damaging their gear.

(3) Retrieval technology

There are several techniques developed for the removal of cuttings piles from the seabed. These include jetting, air lifting, vacuum suction, bucket or grab dredging, or a combination of these. Many of these are just prototypes and limited to shallow waters.

When removing the cuttings from the seabed, resuspension of the pile seems inevitable. The operation will also have a potentially negative impact on the sediments and the benthic communities close to the pile.

This is the only option where the pile is totally removed from the seabed. From an environmental point of view this appears to be an ideal solution as far as the seabed is concerned. The piles will however need to be disposed of somewhere, and it is important that the problem is not just moved to another location.

The whole operation including retrieval, treatment, disposal, and in some cases transportation to another site, can be expensive. In addition, emissions to air may be large.

The cuttings piles will have to be analysed separately. For each of the piles it is important to know the exact contents, the total volume, height and area covered by the pile. The potential impact a cuttings pile can have on an artificial reef depends on where the reef is placed.

It is most likely that the structures will be toppled in place and then put together in a group. The chosen site for an artificial reef will probably be near (or around) one of the platforms which are to be shut down. If the chosen centre of the reef is a production platform, it is important that the reef is placed outside the immediate boundaries of the drill cuttings pile. At the Ekofisk field, this should be to the north-west of the platform, for reasons explained above.

3.3.3 Criteria for suitable locations

The design of the reefs laid out according to the scenarios will achieve to be adjusted to existing platform locations and activities.

The following criteria were considered during the selection process for suitable locations at the Greater Ekofisk area??:

1. location of pipelines;
2. contamination concentration and distribution;
3. location of platforms.

3.3.3.1 Location of pipelines

Pipelines will substantially influence the location of a reef. Two types of pipelines can be distinguished. Local pipelines are only used for a specific platform, or a few platforms, whilst export pipelines run between production fields and hence cross through an area. Pipelines have an expected lifetime of 30 - 50 years. Most pipelines connected to a decommissioned platform will also be unusable for other new platforms in the area.

The location of pipelines, combined with contamination concentrations and distribution information (Figure 3.7a,b,c) are used in this study to determine potential artificial reef locations.

3.3.3.2 Contamination concentration and distribution

Sediment contamination is correlated to the faunal diversity, so the closer to the discharge source, the lower fauna diversity will be. A degradation of the contamination over time, and a distribution of contaminants in the direction of prevailing currents are weighted to find suitable locations.

To evaluate the contamination concentration and distribution differences between the different potential reef sites, four grades have been defined. Based on the assumption that the oceanic current comes from north-west (North Sea Task Force 1993), Figure 3.6 below explains this grading. Figure 3.6 must be seen in connection with figures for contamination concentration and distribution presented in Report 2, Appendix 2.1.

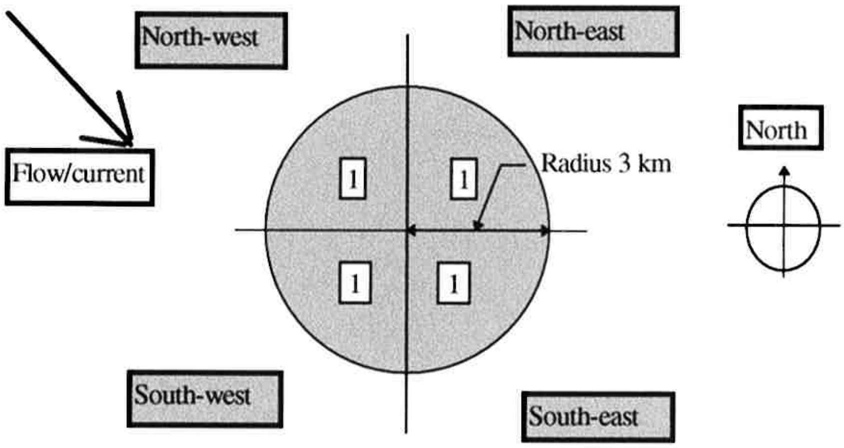

***Figure 3.6**: Grading each potential reef core receives for the contamination concentration and distribution up to 3 km from its centre.*

If a site is contaminated in 2 sectors, then the site is graded 2 on a scale from 1 - 4. For example the Ekofisk tank (Figure 3.7a) is graded 4, since it is exposed to contamination in all 4 sectors around the Centre. Eldfisk 2/7-A (Figure 3.7b) is graded 2, since it has contamination in two sectors (south). Tor (Figure 3.7c) is graded 1, since it has most of its contamination on the south side of the site.

Grading:
1. Contamination in one sector
2. -------«------------ two sectors
3. -------«------------ three sectors
4. -------«------------ four sectors

This grading are used in Table 3.1, presented later in this section. Figures 3.8a,b and c present the combination of contamination distribution and pipelines around the Ekofisk Tank, Eldfisk 2/7-A and Tor 2/4-E.

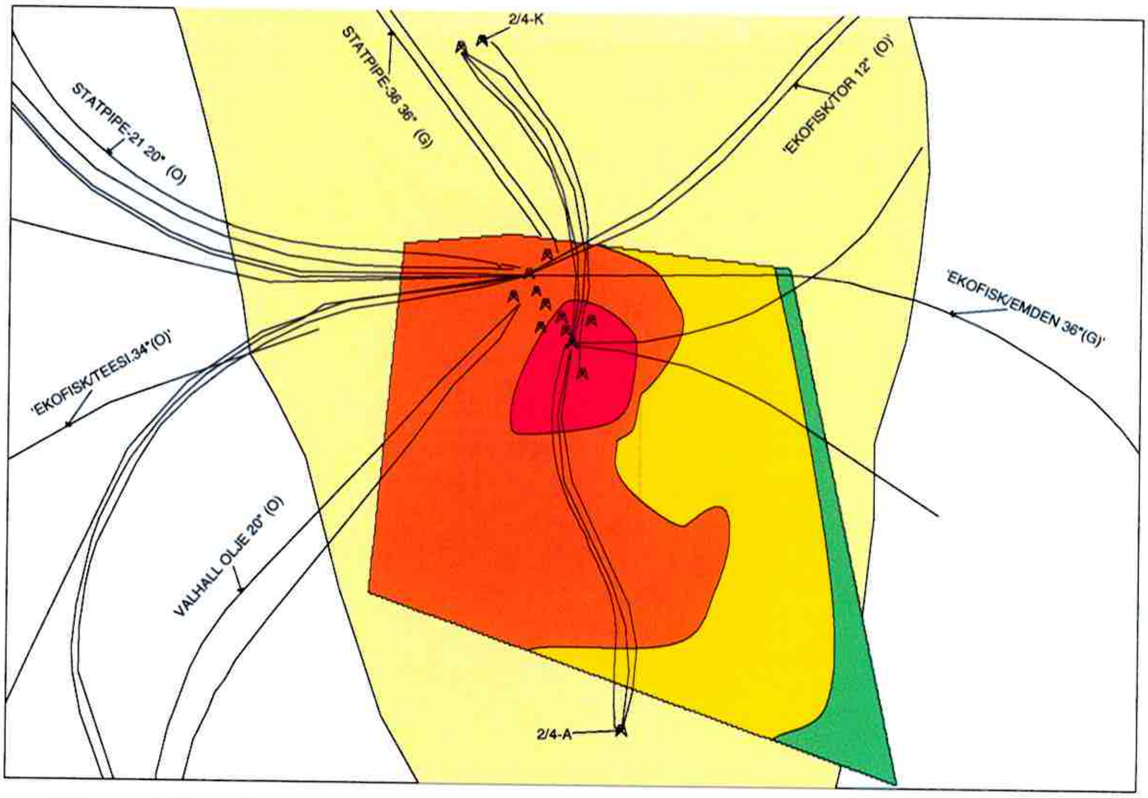

Figure 3.7a: Contamination distribution and pipelines around the Ekofisk Tank.

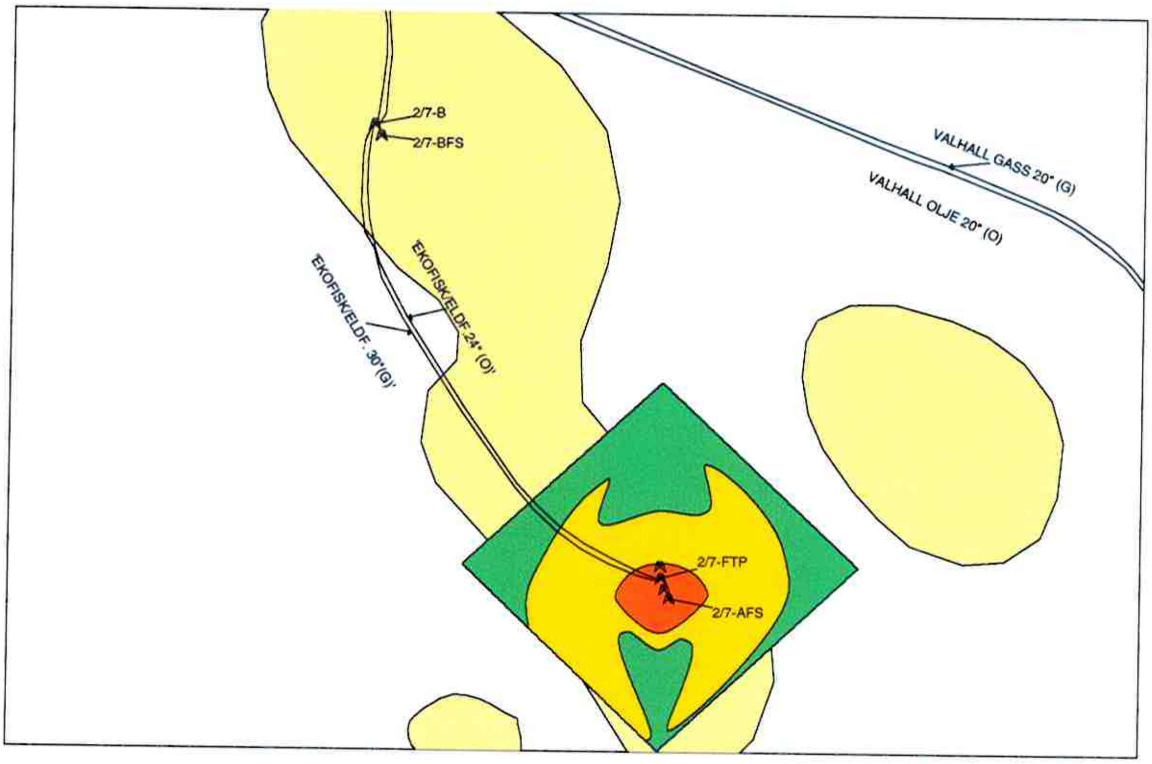

Figure 3.7b: Contamination distribution and pipelines around Eldfisk 2/7-A.

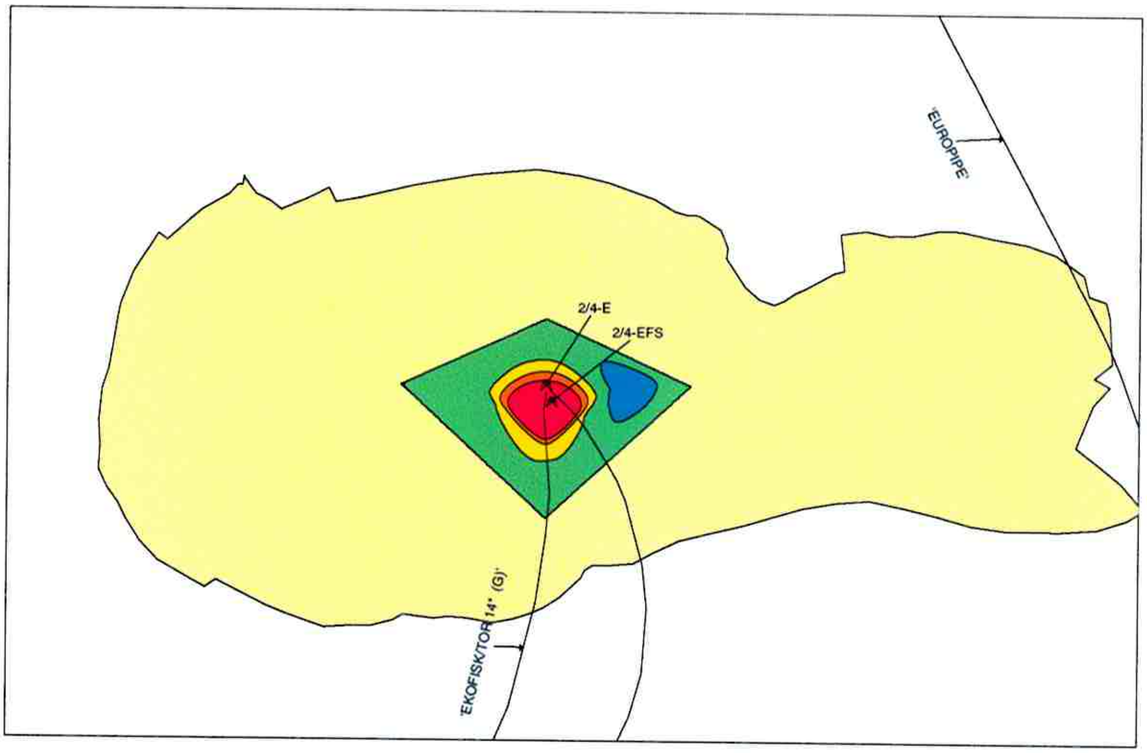

Figure 3.7c: *Contamination distribution and pipelines around Tor 2/4-E.*

3.3.3.3 Location of platforms

At the Greater Ekofisk field, platforms are located in all directions and a range of distances from the Ekofisk Tank. Thirteen of the platforms are located less than 3 km away from the Tank. Four platforms are located west and north-west of the Tank, and 5 platforms are located to the south and south-west. Only one structure is located east, north-east of the Tank. Figure 2.1 in Report 2 shows the locations of each platform.

To minimise the transport of structures required, a site with several structures nearby was sought. Also, the potential for toppling some of the structures was an important consideration. Potential reef sites and their location in relation to other structures are discussed in a broader context in a later section, Criteria for suitable structures.

3.3.4 Evaluation of suitable locations

In Table 3.1, different potential artificial reef sites are presented and evaluated according to suitability based on the above criteria set. The Ekofisk Tank is chosen to be one of the artificial reef sites. The ranking of it in relation to other potential reef sites is included in this Table.

***Table 3.1**: Different potential artificial reef sites are presented and ranked according to suitability based on the criteria set.*

Name	Synonym	Economic lifetime	Location of pipelines, potential problem ?	Contamination concentration and distribution	Location of platform: Unsuitable locations — Reason for not using	Location of platform: Suitable locations — Reason for using
7/11-A	"COD"	1997	no	1	Distance to other platforms	No pipelines, little contamination
1/6-A	"ALBUSKJELL A"	1998	no	1		No pipelines, little contamination, convenient location.
2/7-C	"EDDA"	1998	4.1 km north, Teeside pipeline	1		No pipelines, little contamination, convenient location.
2/4-E	"TOR"	2011	3.6 km north-east, Europipe	1	East side of field, distance to other platforms	No pipelines, little contamination
2/7-B	"ELDFISK B"	2016	1.8 km north-east, Vallhall oil/gas	1		No pipelines, little contamination, convenient location.
2/7-D	"EMBLA"	2016	no	1	Distance to other platforms	No pipelines, little contamination
2/4-D	"VEST EKOFISK"	1998	no	1		No pipelines, little contamination, convenient location.
2/4-F	"ALBUSKJELL F"	1998	no	2	Contamin. from west/north-west	No pipelines, convenient location
2/4-A	"EKOFISK A"	2005	no	2	Contamin. from north/north-west	No pipelines, convenient location
2/4-B	"EKOFISK B"	2005	0.4 km west. Statpipe	2	Contamin. High concentrations	convenient location
2/4-K	"EKOFISK K"	2012	0.6 km, west, Statpipe	2	Contamin. High concentrations	convenient location
"2/7-FTP"		2016	no	2	Contamin. from north/north-west	No pipelines, convenient location
2/7-A	"ELDFISK A"	2016	no	2	Contamin. from north/north-west	No pipelines, convenient location
"2/4-T"	EKOFISK TANK*	1998	yes, several pipelines	4	Contamin. High concentrations	Abandoned at site
	Remaining Platforms*					

* In Table 3.2, all platforms are presented.

3.3.4.1 Ekofisk Tank as a reef site

For the purposes of this study, Ekofisk Tank 3/4T is expected to be abandoned and left in place and used as an artificial reef site. A reef may be created on the north-west side of the Tank. There is a potential problem with using the Tank, because of numerous pipelines, both export and local, from nearby platforms, which still are in production. It is therefore important to avoid any placement of jackets on top of an operational pipeline, whether by toppling in place, or after transport to the site. A high level of safety must be implemented, during reef creation around the Tank.

From an environmental perspective, the Tank is not suitable as an artificial reef site, mainly because of the documented heavy metal and contamination concentration in the area (Jørgensen & Mannvik 1994). The contaminants may though degrade with time. Also, the production has become considerable cleaner in terms of using water-based mud and improved production techniques. The production at Ekofisk 2 may however pose a threat to a reef created around the Tank, in terms of risks of oil-spill or heavy metal accumulation in the biota at the reef.

The Tank is the centre of the Greater Ekofisk field, this in itself, makes it a very suitable location. About 50 % of the platforms are located around the Tank, and this therefore simplifies the reef implementation substantially. In chapter 3.4, *Suitable structures*, an extended description indicates that the sum of weight*distance (kgkm) to move platforms to the Tank is less than for Albuskjell 1/6-A or Eldfisk 2/7-B. Reef implementation efficiency is higher by using the Tank, in comparison with other potential reef sites proposed. Again, the consideration whether its possible to topple in place or the platform must be removed is a very important criteria when a location is chosen. This is discussed extensively in chapter 3.4; *Structures*.

3.3.4.2 Other potential reef sites

Potential reef sites evaluated as the most suitable locations were: Albuskjell 1/6-A, Edda 2/7-C, West Ekofisk 2/4-D and Eldfisk 2/7-B.

(1) Albuskjell 1/6 A

The main reasons for choosing Albuskjell 1/6 A are:

- no problems with interfering pipelines;
- the contamination distribution will generally move east or south-east because of the prevailing currents from the west or north-west;
- the end of its economic lifetime is planned as 1998 and therefore this site provides an available alternative to the Ekofisk Tank.

(2) Eldfisk 2/7 B

The reason for choosing Eldfisk 2/7 B are:

- its convenient location in relation to other platforms;
- the pipeline north and north-east of the site must though be carefully considered;
- pipelines from Valhall are about 1.8 km away, so this should not have any negative impact as long as the reef extends to the west or south-west;
- the contamination distribution is to the south and east of the site, so a reef may therefore be extended to the west and south-west of this core.

(3) Edda 2/7 D and West Ekofisk 2/4 D

The reason for adding Edda 2/7 D and West Ekofisk 2/4 D as alternative options, is the same as for Albuskjell 1/6 A. These two sites are adequate alternative to the two others. The contamination free sectors for these two sites are to the west.

3.3.4.3 Unsuitable reef sites

The reason for not using Cod, Tor and Embla is because they are both at the outskirts of the field. Embla is south of the Eldfisk area, with a potential contamination issue to consider, and it is also new (started production in 1993). Cod and Tor are useful locations, but their distance from other structures, and the fact that there are more platforms to use on the west side of the Tank, makes Cod and Tor unlikely candidates as reef locations.

Albuskjell F, Eldfisk A and Eldfisk FTP may be potential reef sites, but they all are exposed to contamination from platforms to the west or north (Albuskjell A and Eldfisk B). They are convenient locations, but seen from an environmental perspective, they are less suitable than Albuskjell A and Eldfisk B.

The reason for potentially not using Ekofisk A, B, and K are the complex production and export pipelines in the area. However, toppling these platforms in-place appears a viable option, especially economically, which could simplify the reef configuration. The contamination concentration and distribution around these sites are though well documented. There is therefore an indication that these sites may be environmentally suspect as artificial reef sites. The toppling strategy would though reduce some transport costs, and also establish two reference points for a reef site, i.e. the Tank and Ekofisk B/K.

3.3.4.4 Single jacket reef sites

In situ toppling of all structures on the Greater Ekofisk field is an option Phillips Petroleum are considering. Whilst the term *in situ* toppling refers toppling of structures in place, it may be possible to topple them in certain directions, to optimise the reef configuration. Toppling in-place the platforms on the Greater Ekofisk field may be the most economical solution, and could reduce the decommissioning effort considerably.

In situ toppling of all the structures implies that relatively small (compared with a complex reef comprising several structures) artificial reefs are located over a greater area. From a fishery perspective, this may serve to exclude fishing operations in a greater area than if clustered reefs are implemented. This exclusion can be enforced either formally through the continued imposition of a safety zone, through a restricted fishing zone, or in effect through the risk of snagging and loss of gear. The potential hazard to bottom trawl gears as structures degrade could be an impact in the long run. Structures will be chosen to reduce the safety risks associated with the potential for migration from the site.

Previous reports (Cripps *et al.* 1995; Aabel *et al.* 1997) indicate that clustered reefs may serve as the best option for the creation an artificial reef at Ekofisk. The main reason is the perceived, though possibly not actual, need to avoid high contaminant concentrations around the platforms. Removal of platforms from sites with high contamination concentrations to sites with less contamination may be more beneficial for the fauna at and around a new reef, though this is far from certain.

In this report, clustered reefs are the main priority but toppling in-place for certain sites are considered as potential options. In Table 3.4, in addition to the main alternatives, it is suggested that all structures at the Ekofisk Centre are to be toppled in-place when production ceases. This will of course depend on the political decisions at the time, and the environmental perspective, i.e. the level to which the contaminant have degraded.

3.3.5 Sea Bed Restoration

The cuttings pile could be disturbed during operations for all of the abandonment options being considered and, if left in place, is likely to remain a source of contamination for many years. An environmental impact assessment may recommend total or partial removal, treatment or capping of the cuttings pile prior to removal of the jacket.

The environmental impact of existing piles of cuttings has been monitored and there is some information describing and quantifying their physical extent, the concentrations of metals and hydrocarbons in them, and the surrounding sediment, and the effects they produce on the benthic fauna in the vicinity of the platforms (Davies *et al.* 1988).

The following "agreed facts" on the effects of oil-based muds (OBM) summarise present knowledge within the subject.

The discharge of cuttings contaminated with OBMs can lead to:

- increased concentrations of hydrocarbons in the sediment, biota and the water column;
- increased concentrations of mud components such as barium;
- burial or smothering of seabed organisms;
- changes in the populations of benthic organisms, for example, changes in diversity, number of species present and distribution of individuals in the community;
- sublethal effects such as tainting of fish flesh.

The intensity and extent of the adverse effects is determined by the chemical composition, the toxicity, the amount and the method of discharge of the OBM cuttings and their dispersion. Dispersion will be affected by the water depth, tidal and wind induced currents and the general hydrology of the area.

Within two years following the cessation of discharge of cuttings, or a marked decrease in the rate of discharge, several studies have demonstrated that hydrocarbon concentrations in the sediments are reduced and that there is a recovery of the biological populations around the point of discharge. In Dutch studies relating to areas where levels of sediment redistribution are high, such recovery has not been observed within approximately 5 years after cessation of drilling.

3.3.6 Location conclusions and recommendations

1. Various parameters were considered in order to determine potentially suitable reef sites at the Greater Ekofisk field. The main parameters included distance to available structures, proximity to operational structures, field sediment contamination and likely designs (e.g. toppled *in situ* vs. clustering in different forms).
2. The Ekofisk Tank was considered as a suitable location because of its early decommissioning date, large, immovable size and proximity to other platforms. The reef at that site however need to be designed such that the majority of components were placed outside of the heaviest contaminated area around the Tank.
3. Albuskjell 1/6A and Eldfisk 2/7B were also identified as potentially suitable sites, primarily because of the lower sediment contamination (than the Ekofisk Tank area), few pipelines, early decommissioning date and proximity to several platforms.

4. Edda 2/7 D and West Ekofisk 2/4 D may also be suitable locations for reef creation.
5. Toppling in-place so that reefs are located throughout the Ekofisk field is likely to be an economically advantageous strategy, but has some drawbacks associated with optimal reef design, avoidance of contaminated sites and fishing safety.
6. If a reef is to be constructed in the vicinity of a cuttings pile, it is recommended that some form of remediation action, such as retrieval or covering, be taken to prevent the possibility of contamination of the reef biota.
7. Sediment contamination is considered unlikely to be detrimental to reef establishment, especially in the long-term, though the precautionary principle is invoked to waylay any perceived fears of contamination.

3.4 Structures to use at a reef

3.4.1 Introduction

It is believed that the platform jackets will provide a basis for a substantial food chain and that their presence will change relatively unproductive areas into diverse, dynamic and highly productive ecosystems (Driessen 1985). It has been suggested that aspects of the structures geometry may provide resting places and areas of shelter either from predators or strong currents, that the structure may be a suitable spawning site (unlikely at Ekofisk), or a protected area for juveniles, that the physical presence of the structure may provide a point of reference or orientation in the open sea, or that sessile and mobile fouling on the structure may provide a source of food or rare habitat (Cripps et al., 1995).

If the structures and sediments on which the reef are placed, are properly decontaminated prior to reef creation, few negative impacts on the biological community would be expected from the reef. Some leaching of metals will occur when the structures are deteriorating, but negative effects should be negligible (Cripps *et al.* 1995).

The preferred alternative in terms of safety, environmental impacts, cost effectiveness and practicality, will be a combination of several scenarios. Some structures will be toppled in-place while others will be moved to a predetermined location, either immediately or at some later date, eventually to comprise several reef clusters.

3.4.2 Identification of structures

3.4.2.1 Existing facilities

The density and openness of the jacket structures puts them amongst the most stable and durable reusable material readily available for permanent artificial reef construction. In design they approximate the purpose made Japanese reefs that are currently considered to optimal.

The structures will be robust and have a reasonably good integrity. They have an expected life-time of more than 150 years (Kjeilen *et al.,* 1995). If only the steel frame remains, the corrosion and final collapse of the structures will solely depend on the deterioration of the steel frame itself. Iron is the main component of the steel jacket, and this will be deposited and dissolved as the structure starts to deteriorate. Iron is however not considered to be a harmful chemical, and can in some instances actually be considered beneficial to the biological community, because it can be a growth limiting nutrient.

The platforms are expected to be decommissioned over a period of the next 30 years. This has been taken into consideration when locations were chosen (see previous section). Existing facilities at the Greater Ekofisk field and their economic lifetime are presented in Table 3.2.

3.4.2.2 Use of structures other than jackets

The potential for using offshore structures, other than merely jackets as reef components has been evaluated. Four components are sufficiently relevant to be discussed here, due to their structural complexity for use as artificial reef components: flare stacks; bridge supports; bridges; and drilling towers (derricks). Topside modules other than these, including flame booms, are not evaluated because: they are composed of a wide register of material not acceptable to the marine environment; because of their lack of structural complexity; or relatively small size (and would therefore make unstable reef components - section 3.5.6).

Data on these structures are presented in Table 3.2. The evaluation of their suitability and the plan for incorporation of these components is presented in section 3.4.4. *Evaluation of suitable structures.*

All steel structures, including bridges, bridge supports, drilling towers (derrick) and flare stacks have a configuration that is optimal for use as reef components. The quantities (i.e. weight, volume, number) of the non-jacket structures have been calculated and presented in Table 3.2. Each of the main jacket structures serves as a reference point for the other structures that can be used as a reef components.

From Table 3.2. there are several obvious candidate structures suitable for use as artificial reef components at the Greater Ekofisk field (average individual weights and volumes given in brackets):

- 24 main jackets (150,000 m^3, 5400 tonnes);
- 9 flare stacks and 7 bridge supports (13,000 m^3, 900 tonnes);
- 29 bridges (1300 m^3, 300 tonnes);
- 11 drilling towers.

***Table 3.2**: Greater Ekofisk field structure dimensions and their economic lifetimes (dimensions in metres).*

Name	Synonym	Economic Lifetime	Rig type	No legs	Jacket weight	Jacket volume	Height	Width bottom	Length bottom	Width top	Length top	Missing Data
7/11-A	"COD"	1997	"Production Platform"	8	4360	192600	84	44	76	23	54	
"7/11-FL"			"Flare Stack", 7/11-A	3	870	13552	84	37	37	-	-	
			Bridge to flare stack		90	798	4,5	4,5	91			
			Drilling tower									*
1/6-A	"ALBUSKJELL A"	1998	"Production Platform"	12	7320	182300	78	50	65	31	46	
1/6-AFS			Flare stack, 1/6-A	3	920	10011	78	33	33			
			Bridge support, tripod	3	920	10011	78	33	33			
			Bridge #1 to flare stack		333	1746	6	7	96			
			Bridge # 2 to flare stack		333	1564	6	7	86			
			Drilling tower									*
2/4-F	"ALBUSKJELL F"	1998	"Production Platform"	12	7320	182360	78	50	65	31	46	
2/4-FFS			Flare stack, 2/4-F	3	920	10011	78	33	33			
			Bridge support, tripod	3	920	10011	78	33	33			
			Bridge #1 to flare stack		333	1746	6	7	96			
			Bridge # 2 to flare stack		333	1564	6	7	86			
			Drilling tower									*
2/7-C	"EDDA"	1998	"Production Platform"	12	6690	189000	80	50	66	31	46	
2/7-CFS			Flare stack, 2/7-C	3	707	9882	77	33	33			
			Bridge to flare stack		114	1072	5	5	99			
			Drilling tower									*
"2/4-T"	"Ekofisk Tank"	1998	"Process Platform"	-	-	-	90	89	89	89	89	
"2/4-R"		1998	"Riser Platform"	8	3455	119700	84	63	35	43	15	
2/4-RFS			Flare stack, 2/4-R	3	950	24382	93	33	33	11	11	*
			Bridge support, tripod	3	950	24382	93	33	33	11	11	*
			Bridge #1 to flare stack		121	1072	5	5	99			*
			Bridge # 2 to flare stack		121	1072	5	5	99			*
			Bridge to Tank		121	1072	5	5	99			*

- Missing data, or the data are uncertain and need to be confirmed

Table 3.2 (Cont.): Greater Ekofisk field structure dimensions and their economic lifetimes (dimensions in metres).

Name	Synonym	Economic Lifetime	Rig type	No legs	Jacket weight	Jacket volume	Height	Width bottom	Length bottom	Width top	Length top	Missing Data
"2/4-S"		1998	"Riser Platform"	4	7000	92170	82	42	42	22	22	
			Bridge support, tripod	3	1200							*
			Bridge #1 to 2/4R		1100	641	4,2	4,9	71,9			
			Bridge #2 to 2/4R		1100	1293	5	6,6	90,5			
"2/4-P"		1998	"Booster Platform"		1130	69515	83	40	34	15	15	
			Bridge support, tripod	3		12321	96	33	33			*
			Bridge #1 to 2/4C		663	1070	4	6	103			
			Bridge #2 to 2/4C		663	1070	4	6	103			
			Bridge to Tank		181	857	6	6	55			
"2/4-G"		1998	"Riser Platform"	4	1600	62500	-	41	33	21	14	
			Bridge to Tank			2739	6,1	6,1	170			*
2/4-D	"VEST EKOFISK"	1998	"Production Platform"	8	2720	120760	76	37	64	18	45	
			Drilling tower									*
2/4-B	"EKOFISK B"	2005	"Production Platform"	12	5180	151000	76	46	62	27	42	
			Drilling tower									*
"2/4-FTP"		2005	"Process Platform"	12	4780	149700	76	61	46	42	27	
			Bridge support to 2/4W	3	850	10652	83	33	33			
			Bridge # 1 to 2/4W			851	4,5	4,5	97			*
			Bridge # 2 to 2/4W			851	4,5	4,5	97			*
			Bridge to 2/4Q									*
2/4-A	"EKOFISK A"	2005	"Production Platform"	8	3685	134400	76	37	64	18	65	
			Drilling tower									*
"2/4-Q"		1998	"Quarter Platform"	4	1390	69500	83	34	40	21	15	
			Bridge to 2/4C		180	951	6	6	61			
2/4-C	"EKOFISK C"	2009	"Production Platform"	12	6059	184000	83	50	62	31	43	
			Bridge #1 to 2/4X									*
			Bridge #2 to 2/4X									*
			Bridge to 2/4Q									*
			Bridge to 2/4H		250	2546	7	7	120			*
			Drilling tower									*

- Missing data, or the data are uncertain and need to be confirmed

***Table 3.2 (Cont.)**: Greater Ekofisk field structure dimensions and their economic lifetimes (dimensions in metres).*

Name	Synonym	Economic Lifetime	Rig type	No legs	Jacket weight	Jacket volume	Height	Width bottom	Length bottom	Width top	Length top	Missing Data
2/4-E	"TOR"	2011	"Production Platform"	8	5220	176000	78	50	65	23	55	
2/4-EFS			Flare stack, 2/4-E	3	900	12584	78	37	37			
			Bridge to flare stack		90	815	4,5	4,5	93			
			Drilling tower									*
2/4-W	"EKOFISK W"	2012	"Injection Platform"	3	775	39900	76	29	33	9,4	10	*
2/4-WFS			Flare stack, 2/4-W	3	850	21760	83	33	33	11	11	
			Bridge to flare stack		90	851	4,5	4,5	97			
2/4-K	"EKOFISK K"	2012	"Injection Platform"	8	19820	319800	77	67	93	31	67	
			Bridge to 2/4B		495	3017	8,3	7,3	115			
2/7-A	"ELDFISK A"	2016	"Production Platform"	12	6500	182360	78	50	65	31	46	
			Bridge to 2/7-FTP		245	671	5	5	62			
			Drilling tower									*
2/7-B	"ELDFISK B"	2016	"Production Platform"	12	6600	182400	78	50	65	31	46	
"2/7-BFS"			"Flare Stack", 2/7-B	-	925	10011	78	33	33	-	-	
			Bridge to flare stack		115	1104	5	5	102			
2/7-D	"EMBLA"	2016	"Riser Platform"	4	4650	60680	82	30	36	20	20	
"2/7-FTP"		2016	"Process Platform"	8	4400	117400	78	35	65	16	46	
"2/7-AFS"			"Flare Stack",2/7-FTP	3	900	9754	76	33	33	-	-	
			Bridge support, tripod	3	900	9754	76	33	33			
"2/7-ABS"			"Bridge structure"	-	-	1072	5	5	99	-	-	*
"2/4-H"		2028	"Quarter Platform"	4	3258	118000	83	46	46	27	27	
2/4-J		2028	"Production Platform"	8	10000	233000	108	76	40	64	20	*
			Bridge to 2/4X									*
			Drilling tower									*
2/4-X	"EKOFISK X"	2028	"Production Platform"	"4-6"	6300	110000	108	40	40	40	18	*
			Drilling tower									*

* Missing data, or the data are uncertain and need to be confirmed

3.4.2.3 Interaction with operating platforms and risk of decommissioning

There will be a danger of toppling and/or moving operations interfering with operating platform activities. The distance from a decommissioned structure to nearest operating structure will therefore be an important factor to consider. Impacts from accidental spills, ship traffic, etc. associated with operating platforms may also negatively impact on a developing reef structure after a reef is created. The impact increases with proximity to operating structures.

Reef creation of some of the decommissioned platforms may need to be delayed because of ongoing operations at other platforms. Delayed reef creation operations will introduce the need for continued maintenance of "cold", decommissioned structures. Delayed reef creation should reduce costs by permitting co-ordinated engineering work related to toppling and moving of structures.

The continued presence of structures on the seabed may represent a long-term liability for the owner of the platform. The structure may present a risk to fishermen which may be exacerbated if the structure breaks up. Subsidence in the area of Ekofisk field is understood to be approximately 35 centimetres per year. This movement may increase the risk of structural instability and break-up of the placed jacket structures. Risk assessment in this regard are outside the scope of this work, but will need to be defined and assessed at a later date.

Possible environmental and safety impacts from a toppling operation will have to be reduced to a minimum by temporarily reducing production operations as much as possible. The risk can not though be totally eliminated. There will also be a small risk of sea-floor debris, from deteriorating toppled structures, disturbing ongoing field operations, even though reef components should be prepared in a such way as to remove all components that may deteriorate at a fast rate. Only the largest components have been chosen, to avoid the risk of debris migration due to bottom currents. Also leakage of any residual contamination into the water column and sediments may occur. Distance between structures will dominate the assessment of the risk.

The jacket removal technique especially the method of cutting the legs, such as with explosive charges, will have a direct effect on the organisms in the water column and on the sea floor. These effects will almost certainly be localised, but may result for example in fish kills. The whole operation of toppling and removal must be well environmentally assessed prior to implementation. Guidelines for the reef implementation are outside the scope of this report, and are presented in the section *Further Work.* In Report 4, *Environmental impacts*, an extended discussion of these aspects are presented.

3.4.2.4 Stability of structures

It is expected that the structure will be in sufficient water depth, and have a sufficient weight, to resist all anticipated wave and current forces to remain stable on the seabed. Transporting structures above water can be implemented by using controllable buoyancy air bags. The bags will enable the module to be floated out from decommissioned location to the reef site, and to be lowered accurately into position on the seabed. The jacket can be placed vertically or horizontally, and anchors may be used to fix the structure to the seabed as added protection to ensure that it does not roll over or move from its site (Aabel *et al.,* 1997).

In this report, the structures will be toppled or placed so that the horizontal component (i.e. low reef side) will be maximised. The depth below surface vessels will therefore be maximised and the jacket will be better stabilised and have a lower centre of gravity.

Two options for toppling the jackets are considered: either the structure legs will be cut at the base, and loaded down to one side, or the structure will be cut at a given height above the seabed, the remaining top-part will then be placed on its side next to the bottom part. Cutting the structure may give reduced stability, but it is considered that the remaining weight and size is sufficient to ensure that the structure will not drift. The next section will discuss these options in greater detail.

Stability of a structure lying on the seabed may, to a certain extent, be correlated with potential subsidence in the area. The water depth in the Greater Ekofisk area is approximately 70 - 80 m. In the central Ekofisk complex, the depth is, at present 76 m, but this is expected to increase to 90 m by 2040 (Cripps *et al.,* 1995).

Reef components may degrade faster, and be made more unstable because of the subsidence. This effect may however be minor in comparison with the degradation of the structures once the corrosion takes place and the anodes are exhausted.

3.4.2.5 Transportation of jackets vs. toppling in place

(1) Introduction

The Ekoreef report being conducted for PPCoN is investigating the possibility of forming one or more artificial reef units using the Ekofisk jackets. These are likely to be around 2/4T, Albuskjell and Eldfisk. This involves either the removal and transportation, or the toppling in-place of the jackets.

The following section, some of the technical challenges, resource requirements, energy considerations and relative advantages and disadvantages of transportation versus toppling are examined. In compiling this assessment it is assumed that only the Ekofisk I jackets, as defined in the "Ekofisk I Disposal Study - Conceptual Phase" performed by Reverse Engineering Norge, will be considered.

(2) Methods

There are several methods for the removal and transportation of the Ekofisk jackets. These include crane vessels and buoyancy systems, as discussed below. In order to assess these options, information on jacket weights has been taken from the "Ekofisk I Disposal Study - Conceptual Phase" performed by Reverse Engineering Norge.

The jacket weights used are as follows and included jacket and pile (above the mud-line) weights unless stated otherwise:

Cod 7/11A	4,360 tonnes	Ekofisk 2/4G	2,014 tonnes
Edda 2/7C	6,690 tonnes	Ekofisk 2/4P	1,420 tonnes
West Ekofisk 2/4D	2,720 tonnes	Ekofisk 2/4R	3,455 tonnes
Albuskjell 1/6A	7,320 tonnes	Ekofisk 2/4S	7,000 tonnes (excl. piles)
Albuskjell 2/4F	7,320 tonnes		

In addition to the above steel structures, there are 10 tripods. The tripod jacket weights are about 700 - 800 tonnes (including piles).

(3) Crane Vessels

Crane vessels could be used to remove and relocate the jackets to the designated reef site. The three reef sites are all relatively central and in close proximity to the majority of the structures (i.e. within about 25 km). The only exceptions to this are Cod (80 km) and the oil/gas boosters. It would therefore may be feasible to cut the piles, lift the jackets and transport them on the hook of the crane vessel for placement at the reef site.

The most cost effective method of employing crane vessels to undertake this operation will be to lift the jackets in one piece. All Ekofisk jackets can be totally relocated in a one piece lift using an Semi Submersible Crane Vessel (SSCV), as shown in Figure 3.8.

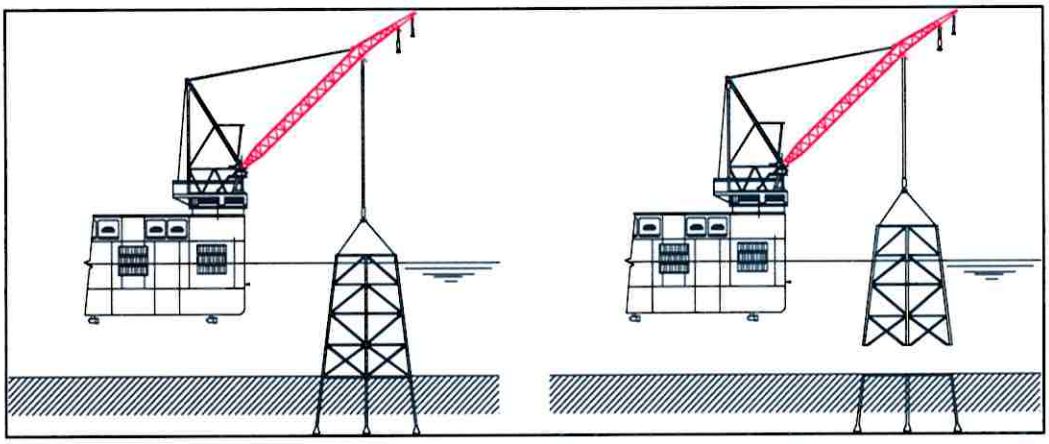

Figure 3.8: *Removal of jackets using an* Semi Submersible Crane Vessel *(SSCV)*

Lifting in one piece using a mono-hull HLV is not possible for the 12-legged and 8-legged jackets, due to excessive weight and lifting height. In addition, although the weight of the 4-legged jacket 2/4P makes it possible for a mono-hull crane vessel to lift it, the height of the structure also rules out the option of lifting the jacket in one piece.

(4) Buoyancy

Buoyancy systems could, in theory, be used to remove the jackets and place them at a reef location. These methods however do require further research and development. This scenario envisages a one piece floatation of the jacket by providing buoyancy to it either by bags, tanks or foam. Various combinations exist, using a combination of buoyancy bags filling the inside of the jacket frame, attaching buoyancy tanks to the jacket legs and filling the jacket legs with foam. The buoyant structure is then towed to the final destination.

A new innovative concept, the Controlled Variable Buoyancy System (CVBS) has recently come on to the decommissioning market. This CVBS is currently under development as a joint industry report (JIP) for the total removal of offshore heavy steel jackets and their towing to the reef site.

The main objectives of the JIP are:

- to develop an underwater heavy lift system for the purpose of removing steel jacket structures from the seabed and towing to a final destination;
- to demonstrate that the CVBS may be a technically viable alternative to other existing methods of platforms decommissioning;
- to demonstrate the safety and reliability of the system;
- to demonstrate the controllability of the system.

The CVBS is an alternative method to conventional techniques. Major cost savings may be possible because no heavy lift spread is required and, for larger jackets, the CVBS removes the need to remove jackets in sections. Preliminary studies indicate potential cost savings of 64 % when compared to removing a typical (<1500 tonne) jacket using heavy lift vessels.

The general approach in developing this CVBS is not new; it uses the concept of buoyant systems and as such, can be considered in the context of currently available buoyancy technology, including parachute systems, closed cell rigid foams and non-variable inflatable bag systems.

Qualitative comparisons favour the CVBS concept and show it to have advantages over all the existing technologies in one or more areas of cost, weight capacity, stability, controllability and contingency.

The novelty and significant technological advances over these existing systems would be the development of the autonomous controllability of the buoyant lifting systems with respect to speed, acceleration, momentum and ambient pressures. This will allow the recovery of the jacket structures during the removal phase remotely, in a controlled manner and with minimum risk to personnel. In addition, the CVBS will incorporate a contingency system which will enable redundant elements to inflate and thus react to any loss of buoyancy provoked by the rupture of some buoyancy modules.

The CVBS consists of modular buoyancy units around a steel tubular backbone. The CVBS is designed to act as primary or secondary buoyancy for the jacket and the buoyancy units are installed along the diagonal bracing on the jacket, see Figure 3.9.

Once the topsides have been removed and the jacket piles excavated (if necessary), auxiliary friction grip clamps and support slides, see Figure 3.10, are installed around the exposed pile. These clamps are designed to provide structural stability once the piles are cut.

After cutting the piles the CVBS units are inflated and tow lines attached to the structure. As positive buoyancy is gained, the jacket rises in the water. Control of the initial ascent is established and maintained by monitoring the relative motion at the slide mechanisms. Once under control, the jacket is decoupled from the pile by firing the explosive bolts on the slider assembly.

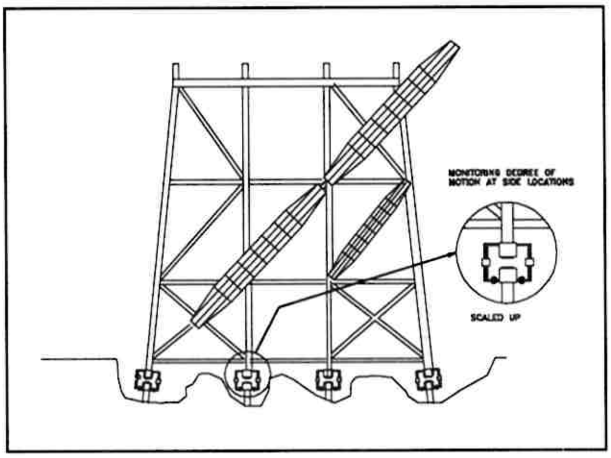

Figure 3.9*: Installation of CVBS*

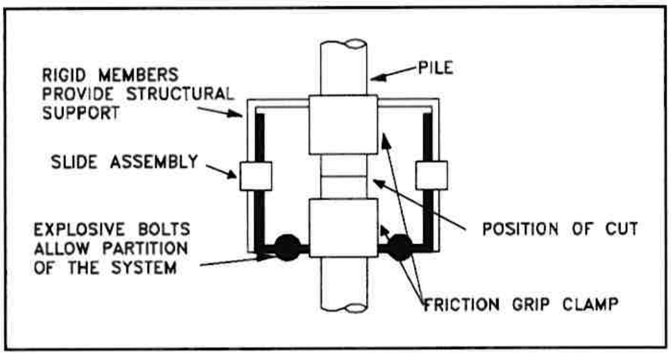

Figure 3.10*: Friction Grip Clamp / Support Slides*

The jacket ascent and trim is computer controlled from the towing vessel until the jacket is in a suitable towing position (see Figure 3.11). From here, the jacket is towed to the reef site and placed on the seabed by controlled ballasting of the buoyancy system. The CVBS units can then be recovered. Alternatively, the CVBS units could be left on the jackets for future removal of the reefed structures if required.

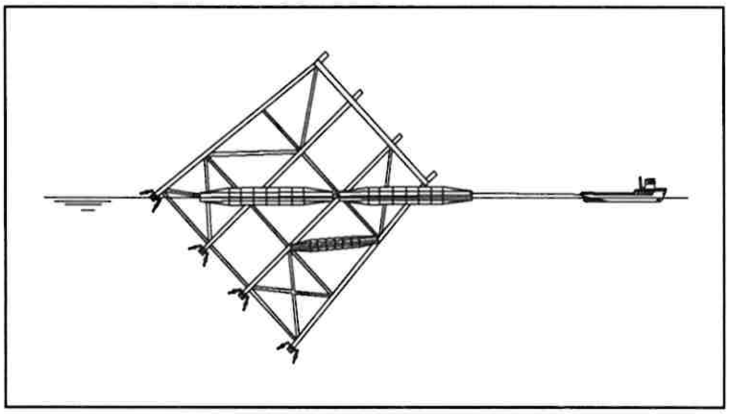

***Figure 3.11**: Floated Jacket*

(5) Toppling

Toppling involves a deconstruction operation, in which the jacket rotates about a pre-determined position and collapses in a controlled manner onto the seabed. There are two main categories of toppling:

- 'pull-over', which involves cutting the jacket or piles and toppling with assistance from tugs, pull barges etc.;
- unassisted or gravity toppling where the toppling process is induced by the cutting of the jacket. It is self-sustaining due to the load distribution of the jacket.

Toppling, where suitable, can provide a technically feasible, cost effective solution for the decommissioning of oil/gas structures. The main advantages of toppling a jacket *in-situ* are:

- minimal offshore spread is required;
- reduced financial cost;
- reduced risk to personnel;
- structure transportation eliminated.

Due to their shape and height, it is unlikely that toppling of even the relatively heavier structures could be easily carried out unassisted.

There are numerous conceivable ways in which toppling may be achieved and the first choice is whether total or partial toppling should be undertaken. Total toppling (see Figure 3.12) involves cutting the piles below the mud-line (to a depth of about 5 m) and pulling over the structure onto the seabed. This could involve the excavation of sediments and drill cuttings from around the jacket legs to allow access for explosive cutting charges to be placed, if internal placement is not feasible.

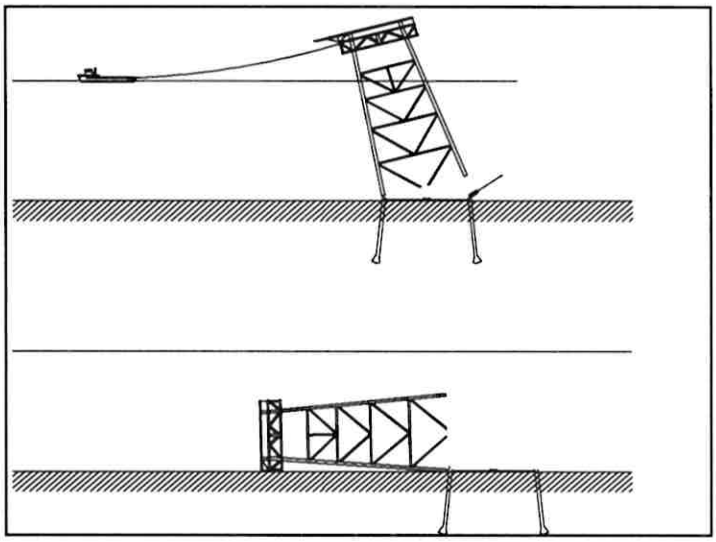

***Figure 3.12**: Total Toppling*

Partial toppling is the toppling of the top section of the structure only, by cutting at a specified depth below sea level (see Figure 3.13).

Total toppling may be favourable in circumstances where the jackets may need to be removed in the future. Total toppling also allows for the possibility of relocating jackets following toppling. In this scenario, a toppled jacket could be relocated by crane vessel or buoyancy systems. It is however unlikely that this will offer any cost advantages over relocating the jackets without toppling. An alternative option, which could be technically feasible and cost effective, may be to topple the jacket and remove it by winching the jacket underneath a pull barge for relocation at a reef site (see Figure 3.14).

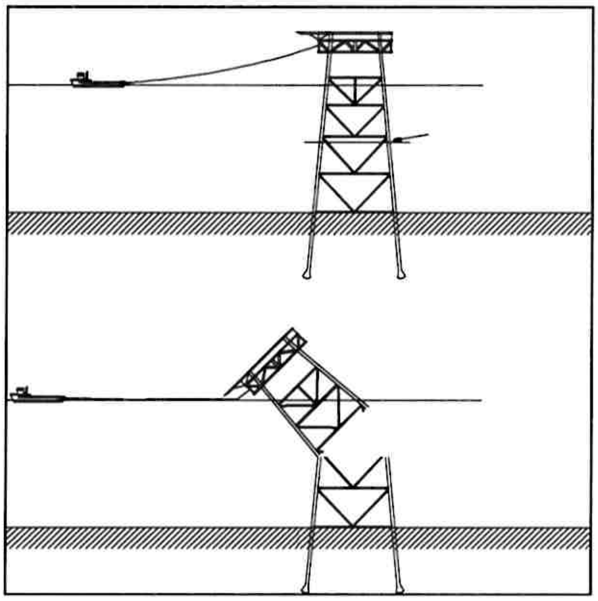

***Figure 3.13**: Partial Toppling*

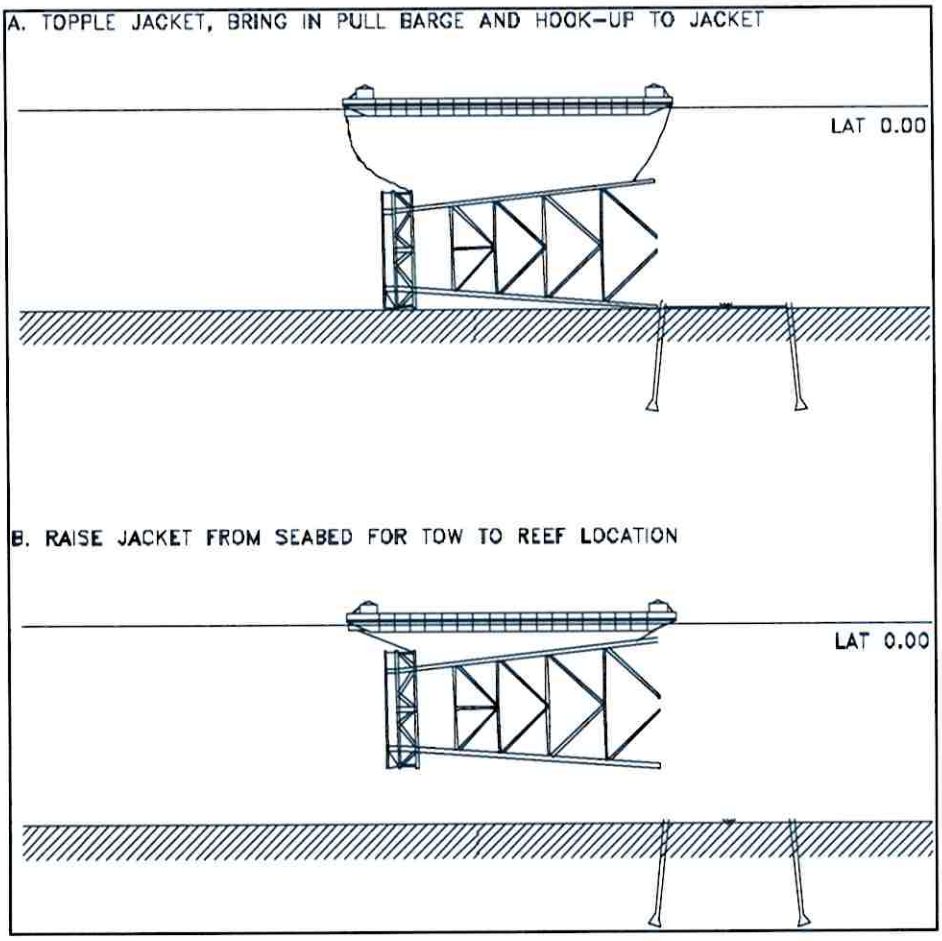

***Figure 3.14**: Toppling and Relocation of Jacket using Pull Barge*

(6) Advantages and Disadvantages

The relative advantages and disadvantages of each method are summarised in the Table 3.3.

***Table 3.3:** The relative advantages and disadvantages of each method are summarised.*

Option	Advantages	Disadvantages
Relocate by SSCV	One piece lift of all steel jackets is technically achievable.	Cost of SSCV for initial placement at reef site. Cost of SSCV if required to remove the jackets in the future. Most expensive in terms of energy consumption.
Relocate by buoyancy	Buoyancy systems can be left on jacket, or re-installed for future removal. Piles can be cut with buoyancy systems installed. Cheaper than using SSCVs.	Technology requires proving.
Topple and Relocate	Available technology. Cheaper than using SSCVs.	Possible limits to barge capacity - may require additional winches/upgrading. Assisted topple is required.
Total Topple in Place	Low energy consumption. Relatively inexpensive.	Assessment of the pulling force required to topple is needed. Assisted topple is required.
Partial Topple in Place	Low energy consumption. No need to cut piles. Relatively inexpensive.	Any need to remove the jacket in the future would entail more work and more cost. Assisted topple is required.

(7) Conclusions

The following conclusions have been made:

- Buoyancy systems such as the CVBS would provide ideal solutions for the jacket relocation but require further research and development.
- The relocation of jackets using an SSCV is technically achievable but may be very expensive, both in terms of financial and energy costs.
- Total toppling the jacket in-place would be the most economical solution if permitted.
- If relocation of the jacket is required following toppling, this could theoretically be achieved using a pull-barge. This option however requires further evaluation, but would probably be more cost effective than using an SSCV.
- Partial toppling in-place would avoid the need to cut the piles below the mud-line. In the event future removal of the jacket was required, this would be the most costly option as the piles would still have to be cut and two jacket sections would have to be removed from the seabed.

3.4.3 Criteria for suitable structures

The criteria for choosing suitable structures for the Ekofisk Tank and other potential reef sites are presented first. Suitable structures to use at different reef sites are then evaluated. This section takes into consideration each structure and its suitability as an element at one of the potential reef core locations. The criteria are as follows:

1. volume and structural complexity of jacket;
2. toppling in place or transport of jacket;
3. economic lifetime of jacket.

3.4.3.1 Jacket volume and structural complexity

A large enclosed useable volume for attracting fish and a high structural complexity for protection and faunal community development, have the highest priorities when choosing suitable structures.

An assumption is that the greater volume, the more legs, and therefore also the greater the complexity of the structure. The most important criteria from a fish attraction perspective, is the total volume of the artificial reef complex, i.e. number of jacket at the core.

The volume and complexity of each jacket are graded from 1 to 3, based on the volume of each jacket presented in Table 3.2:

1. Volume of jacket > 150,000 m^3
2. 150,000 m^3 > volume of jacket > 100,000 m^3
3. 100,000 m^3 > volume of jacket

3.4.3.2 Toppling in place or transport of jacket

(1) Toppling in place considerations

Reef sites are placed in the vicinity of some platforms, so avoiding the need to move all structures. This will reduce costs as well as disturbance to seabed and existing biological communities. As with the toppling operation costs however, co-ordinated operations, i.e. moving several structures in the same period of time, would be expected to reduce expenses, because special equipment and expertise can be used more efficiently and with more continuity (Cripps *et al.,* 1995).

(2) Transport of jackets considerations

By transporting jackets, the most unfavourable sites will be avoided. A benefit of transporting the structures in the long run is the less hindrance to the fishing industry because the total area covered by reefs and surrounding avoidance zones will be less, and also more defined.

The jackets will be disconnected from the sea bed and transported, either above or below water. These structures will be placed in a juxta-position, producing an overall design that optimises the reef (see next "design" chapter).

To be able to rank these structures against each other, the weight (kg) of each structure is multiplied with the distance the structure must be transported (km).

Grading:

0. Toppling in place
1. Weight*Distance < 200,000 kgkm
2. 200,000 kgkm < Weight*Distance < 300,000 kgkm
3. 300,000 kgkm < Weight*Distance

This ranking is based on the distinct change in weight*distance at 200,000 kgkm and at 300,000 kgkm. Toppling in place is the most favourable option in this respect. Most the values were in the range of 200,000 kgkm. There was then a distinct separation to the next two gradings. Only few structures, were in the high weight*distance grading. The calculations and ranking for all options considered are presented in Tables 3.4 - 3.8.

3.4.3.3 Economic lifetime of jackets

The economic lifetime for platforms may change, depending on exploration and production results each year. In this study, the platforms are divided into two groups: those that are currently expected to be decommissioned in 1998-2005; and those that are expected to be decommissioned after 2005.

3.4.4 Evaluation of suitable structures

3.4.4.1 Structures to use in alternatives

Six alternatives are discussed and presented in this study. A more detailed description is presented below.

(1) Alternative 1: (Centre)

The reef creation can be implemented using structures as they become available until all of the platforms are decommissioned, after 2028. 13 jackets can be toppled in place and 11 jackets will be placed in a complex reef at the desired location at the Ekofisk Centre. Structures to be used are presented in Table 3.4.

(2) Alternative 2: (Tank, Eldfisk)

Phase 1: A reef will be created north-west of the Ekofisk Tank containing structures that will be decommissioned in the period 1998 - 2005. Six jackets will be toppled in place, and 7 jackets will be placed on the north-west side of the Tank.

Phase 2: After 2005 there are 11 platforms left at the Greater Ekofisk field, 10 will be placed to the west of Eldfisk 2/7-B. Eldfisk 2/7-B will be toppled in-place.

Structures to use are presented in Table 3.5.

(3) Alternative 3: (Centre, Tank)

Phase 1: A reef will be created at Ekofisk B/K containing structures that will be decommissioned in the period 1998 - 2005. Six jackets will be toppled in place, and 7 jackets will be placed at Ekofisk B/K.

Phase 2: After 2005 there are 11 platforms remaining, including Eldfisk 2/7-B. Five platforms will be transported to the Ekofisk Tank, and six platforms will be toppled in-place when the whole field is closed down.

Structures to use are presented in Table 3.6.

(4) Alternative 4: (Albuskjell, Eldfisk)

Phase 1: Structures decommissioned in the period 1998 - 2005 will be placed at the Albuskjell 1/6-A reef site. Albuskjell 1/6-A can be toppled, and hence 12 platforms will be moved up to this site.

Phase 2: After 2005 there are 11 platforms left at the Greater Ekofisk field, 10 will be placed to the west of Eldfisk 2/7-B. Eldfisk 2/7-B will be toppled.

Structures to use are presented in Table 3.7.

(5) Alternative 5: (Albuskjell, Tank)

Phase 1: Structures decommissioned in the period 1998 - 2005 will be placed at the Albuskjell 1/6-A reef site. Albuskjell 1/6-A can be toppled, and hence 12 platforms will be moved up to this site.

Phase 2: After 2005 there are 11 platforms remaining, including Eldfisk 2/7-B. Five platforms will be transported to the Ekofisk Tank, and six platforms will be toppled in place when the whole field is closed down.

Structures to use are presented in Table 3.8.

*(6) Alternative 6 (*In situ *toppling)*

In situ toppling, i.e. all platforms at the Greater Ekofisk Field will be toppled in-place as they are decommissioned. Platforms around the Ekofisk Tank may be toppled in predetermined directions to optimise the reef configuration as much as possible.

A discussion of this alternative is presented in section 3.3.4.4; Single Jacket reef sites. Structures to use are the same as described for alternative 1, which is presented in Table 3.4.

Within each of the first 5 main Alternatives, both a habitat protection design (p) and a fishing design (f) are presented. For habitat protection, the structures will be positioned in one or more circles. For fishing enhancement, the structures will be positioned linearly, thus allowing trawl activity and maximum access to the reefs.

***Table 3.4**: Structures to use for Alternative 1, Ekofisk Tank as reef site.*

Name	Synonym	Economic	Toppling	Jacket	Volume &	Jacket	Distance	Weight * distance	Rank	Sum
		Lifetime	possible ?	volume	Complexity	weight	to 2/4 T	kg*km	weight*distance	.
"2/4-R"		1998	yes	119700	2	3455	0	0	0	2
"2/4-S"	(Statoil)	1998	yes	92170	3	7000	0	0	0	3
"2/4-P"		1998	yes	69515	3	1130	0	0	0	3
"2/4-G"	(Amoco)	1998	yes	62500	3	1600	0	0	0	3
"2/4-FTP"		2005	yes	149700	1	4780	0	0	0	1
2/4-B	"EKOFISK B"	2005	yes	151000	1	5180	0	0	0	1
"2/4-Q"		2005	yes	69500	3	1390	0	0	0	3
2/4-C	"EKOFISK C"	2009	yes	184000	1	6059	0	0	0	1
2/4-K	"EKOFISK K"	2012	yes	319800	1	19820	0	0	0	1
2/4-W	"EKOFISK W"	2012	yes	39900	3	775	0	0	0	3
2/4-J	"EKOFISK J"	2028	yes	233000	1	10000	0	0	0	1
"2/4-H"		2028	yes	118000	2	3258	0	0	0	2
2/4-X	"EKOFISK X"	2028	yes	110000	2	6300	0	0	0	2
7/11-A	"COD"	1997	no	192600	1	4360	75,4	328869	3	4
1/6-A	"ALBUSKJELL A"	1998	no	182300	1	7320	20	143263	1	2
2/4-F	"ALBUSKJELL F"	1998	no	182360	1	7320	12,4	90977	1	2
2/7-C	"EDDA"	1998	no	189000	1	6690	11,4	76457	1	2
2/4-D	"VEST EKOFISK"	1998	no	120760	2	2720	7,9	21371	1	3
2/4-A	"EKOFISK A"	2005	no	134400	2	3685	3,0	11055	1	3
2/4-E	"TOR"	2011	no	176000	1	5220	12,3	64131	1	2
2/7-A	"ELDFISK A"	2016	no	182360	1	6500	19,6	127214	1	2
2/7-B	"ELDFISK B"	2016	no	182400	1	6600	14,4	95229	1	2
"2/7-FTP"		2016	no	117400	2	4400	19,6	86114	1	3
2/7-D	"EMBLA"	2016	no	60680	3	4650	24	111600	1	4

***Table 3.5**: Structures to use for Alternative 2, phase1: Reef creation at the Tank with structures decommissioned. in 1998-2005. Phase 2: after 2005, Eldfisk 2/7 B as a reef site, Eldfisk 2/7-B will be toppled in-place.*

Name	Synonym	Economic Lifetime	Toppling possible ?	Jacket volume (m3)	Volume & Complexity (gr)	Jacket weight	Distance to (km)	Weight * distance (kg * km)	Rank weight * distance	Sum
"2/4-R"		1998	yes	119700	2	3455	0	0	0	2
"2/4-S"	(Statoil)	1998	yes	92170	3	7000	0	0	0	3
"2/4-P"		1998	yes	69515	3	1130	0	0	0	3
"2/4-G"	(Amoco)	1998	yes	62500	3	1600	0	0	0	3
"2/4-Q"		2005	yes	69500	3	1390	o	0	0	3
2/4-B	"EKOFISK B"	2005	yes	151000	1	5180	0	0	0	1
7/11-A	"COD"	1997	no	192600	1	4360	75.4	328869	3	4
1/6-A	"ALBUSKJELL A"	1998	no	182300	1	7320	19.6	143263	1	2
2/4-F	"ALBUSKJELL F"	1998	no	182360	1	7320	12.4	90977	1	2
2/7-C	"EDDA"	1998	no	189000	1	6690	11.4	76457	1	2
2/4-D	"VEST EKOFISK"	1998	no	120760	2	2720	7.9	21371	1	3
"2/4-FTP"		2005	no	149700	1	4780	0.4	2049	1	2
2/4-A	"EKOFISK A"	2005	no	134400	2	3685	3.0	11055	1	3
Phase 2										
2/7-B	"ELDFISK B"	2016	yes	182400	1	6600	0	0	0	1
2/4-C	"EKOFISK C"	2009	no	184000	1	6059	14.3	86557	1	2
2/4-E	"TOR"	2011	no	176000	1	5220	25.6	133483	1	2
2/4-K	"EKOFISK K"	2012	no	319800	1	19820	16.3	322783	3	4
2/4-W	"EKOFISK W"	2012	no	39900	3	775	14.3	11083	1	4
2/7-A	"ELDFISK A"	2016	no	182360	1	6500	5.6	36214	1	2
"2/7-FTP"		2016	no	117400	2	4400	5.6	24514	1	3
2/7-D	"EMBLA"	2016	no	60680	3	4650	9.6	44507	1	4
2/4-J	"EKOFISK J"	2028	no	233000	1	10000	14.3	143000	1	2
"2/4-H"		2028	no	118000	2	3258	14.3	46543	1	3
2/4-X	"EKOFISK X"	2028	no	110000	2	6300	14.3	90090	1	3

***Table 3.6**: Structures to use for Alternative3, phase1: Reef creation at the Tank with structures decommissioned. in 1998-2005. Phase 2: Five platforms will be transported to the Ekofisk Tank, and six platforms will be toppled in-place when the whole field is closed down.*

Name	Synonym	Economic Lifetime	Toppling possible ?	Jacket volume (m3)	Volume & Complexity (g)	Jacket weight	Distance to (km)	Weight * distance (kg * km)	Rank weight * distance	Sum
"2/4-R"		1998	yes	119700	2	3455	0	0	0	2
"2/4-S"	(Statoil)	1998	yes	92170	3	7000	0	0	0	3
"2/4-P"		1998	yes	69515	3	1130	0	0	0	3
"2/4-G"	(Amoco)	1998	yes	62500	3	1600	0	0	0	3
"2/4-Q"		2005	yes	69500	3	1390	o	0	0	3
2/4-B	"EKOFISK B"	2005	yes	151000	1	5180	0	0	0	1
7/11-A	"COD"	1997	no	192600	1	4360	75.4	328869	3	4
1/6-A	"ALBUSKJELL A"	1998	no	182300	1	7320	19.6	143263	1	2
2/4-F	"ALBUSKJELL F"	1998	no	182360	1	7320	12.4	90977	1	2
2/7-C	"EDDA"	1998	no	189000	1	6690	11.4	76457	1	2
2/4-D	"VEST EKOFISK"	1998	no	120760	2	2720	7.9	21371	1	3
"2/4-FTP"		2005	no	149700	1	4780	0.4	2049	1	2
2/4-A	"EKOFISK A"	2005	no	134400	2	3685	3.0	11055	1	3
Phase 2										
2/4-C	"EKOFISK C"	2009	yes	184000	1	6059	0	0	0	1
2/4-E	"TOR"	2011	no	176000	1	5220	12.3	64131	1	2
2/4-W	"EKOFISK W"	2012	yes	39900	3	775	0	0	0	3
2/4-K	"EKOFISK K"	2012	yes	319800	1	19820	0	0	0	1
2/7-A	"ELDFISK A"	2016	no	182360	1	6500	19.6	127214	1	2
2/7-B	"ELDFISK B"	2016	no	182400	1	6600	14.4	95229	1	2
"2/7-FTP"		2016	no	117400	2	4400	19.6	86114	1	3
2/7-D	"EMBLA"	2016	no	60680	3	4650	24.0	111600	1	4
"2/4-H"		2028	yes	118000	2	3258	0	0	0	2
2/4-J	"EKOFISK J"	2028	yes	233000	1	10000	0	0	0	1
2/4-X	"EKOFISK X"	2028	yes	110000	2	6300	0	0	0	2

***Table 3.7**: Structures to use for Alternative 4, phase 1, Albuskjell 1/6-A as reef site with platforms decommissioned in 1998-2005. Phase 2: after 2005, Eldfisk 2/7 B as a reef site, Eldfisk 2/7-B will be toppled in-place.*

Name	Synonym	Economic Lifetime	Toppling possible ?	Jacket volume (m3)	Volume & Complexity (gr)	Jacket weight	Distance to (km)	Weight * distance (kg * km)	Rank weight * distance	Sum
7/11-A	"COD"	1997	no	192600	1	4360	56.6	246776	1	2
1/6-A	"ALBUSKJELL A"	1998	yes	182300	1	7320	o	o	o	1
2/4-F	"ALBUSKJELL F"	1998	no	182360	1	7320	8.0	58560	1	2
2/7-C	"EDDA"	1998	no	189000	1	6690	22.1	148136	1	2
2/4-D	"VEST EKOFISK"	1998	no	120760	2	2720	12.4	33728	1	3
"2/4-R"		1998	no	119700	2	3455	19.4	67126	1	3
"2/4-S"	(Statoil)	1998	no	92170	3	7000	19.4	136000	1	4
"2/4-P"		1998	no	69515	3	1130	19.4	21954	1	4
"2/4-G"	(Amoco)	1998	no	62500	3	1600	19.4	31086	1	4
"2/4-FTP"		2005	no	149700	1	4780	19.4	92869	1	2
2/4-B	"EKOFISK B"	2005	no	151000	1	5180	18.3	94720	1	2
2/4-A	"EKOFISK A"	2005	no	134400	2	3685	21.9	80544	1	3
"2/4-Q"		2005	no	69500	3	1390	19.4	27006	1	4
Phase 2										
2/7-B	"ELDFISK B"	2016	yes	182400	1	6600	0	0	0	1
2/4-C	"EKOFISK C"	2009	no	184000	1	6059	14.3	86557	1	2
2/4-E	"TOR"	2011	no	176000	1	5220	25.6	133483	1	2
2/4-K	"EKOFISK K"	2012	no	319800	1	19820	16.3	322783	3	4
2/4-W	"EKOFISK W"	2012	no	39900	3	775	14.3	11083	1	4
2/7-A	"ELDFISK A"	2016	no	182360	1	6500	5.6	36214	1	2
"2/7-FTP"		2016	no	117400	2	4400	5.6	24514	1	3
2/7-D	"EMBLA"	2016	no	60680	3	4650	9.6	44507	1	4
2/4-J	"EKOFISK J"	2028	no	233000	1	10000	14.3	143000	1	2
"2/4-H"		2028	no	118000	2	3258	14.3	46543	1	3
2/4-X	"EKOFISK X"	2028	no	110000	2	6300	14.3	90090	1	3

***Table 3.8**: Structures to use for alternative 5 phase 1, Albuskjell 1/6-A as reef site with platforms decommissioned in 1998-2005., Phase 2: after 2005, five platforms will be transported to the Ekofisk Tank, and six platforms will be toppled in place when the whole field is closed down.*

Name	Synonym	Economic Lifetime	Toppling possible ?	Jacket volume	Volume & Complexity	Jacket weight	Distance to (km)	Weight * distance kg*km	Rank weight*distance	Sum
7/11-A	"COD"	1997	no	192600	1	4360	56.6	246776	1	2
1/6-A	"ALBUSKJELL A"	1998	yes	182300	1	7320	o	o	o	1
2/4-F	"ALBUSKJELL F"	1998	no	182360	1	7320	8.0	58560	1	2
2/7-C	"EDDA"	1998	no	189000	1	6690	22.1	148136	1	2
2/4-D	"VEST EKOFISK"	1998	no	120760	2	2720	12.4	33728	1	3
"2/4-R"		1998	no	119700	2	3455	19.4	67126	1	3
"2/4-S"	(Statoil)	1998	no	92170	3	7000	19.4	136000	1	4
"2/4-P"		1998	no	69515	3	1130	19.4	21954	1	4
"2/4-G"	(Amoco)	1998	no	62500	3	1600	19.4	31086	1	4
"2/4-FTP"		2005	no	149700	1	4780	19.4	92869	1	2
2/4-B	"EKOFISK B"	2005	no	151000	1	5180	18.3	94720	1	2
2/4-A	"EKOFISK A"	2005	no	134400	2	3685	21.9	80544	1	3
"2/4-Q"		2005	no	69500	3	1390	19.4	27006	1	4
Phase 2										
2/4-C	"EKOFISK C"	2009	yes	184000	1	6059	0	0	0	1
2/4-E	"TOR"	2011	no	176000	1	5220	12.3	64131	1	2
2/4-W	"EKOFISK W"	2012	yes	39900	3	775	0	0	0	3
2/4-K	"EKOFISK K"	2012	yes	319800	1	19820	0	0	0	1
2/7-A	"ELDFISK A"	2016	no	182360	1	6500	19.6	127214	1	2
2/7-B	"ELDFISK B"	2016	no	182400	1	6600	14.4	95229	1	2
"2/7-FTP"		2016	no	117400	2	4400	19.6	86114	1	3
2/7-D	"EMBLA"	2016	no	60680	3	4650	24.0	111600	1	4
"2/4-H"		2028	yes	118000	2	3258	0	0	0	2
2/4-J	"EKOFISK J"	2028	yes	233000	1	10000	0	0	0	1
2/4-X	"EKOFISK X"	2028	yes	110000	2	6300	0	0	0	2

3.4.4.2 *Structures useful around the Ekofisk Tank*

The creation of a reef around the Tank will comprise platforms from the vicinity. The majority of these platforms could be toppled in-place, to avoid transportation to other potential reefs. Toppling in-place is therefore the main placement priority. Table 3.4 - 3.8 indicate that certain structures are more suitable than others with respect to their volume and complexity and their weight x distance factor.

For Alternative 1, where the reef creation will be implemented as the platforms become available, all the structures have a good chance of becoming part of a large, complex artificial reef. Cod and Embla have the lowest grading (4), primarily because of their distance to the Centre, but they still will serve as good components.

For Alternative 2, where the reef creation will be implemented in the period 1998 - 2005, the following structures should be toppled in-place, or moved to the Ekofisk Centre: 2/4-S, 2/4-G and 2/4-P. 1/6-A, 2/4-F, 2/7-C, 2/4-FTP, 2/4-Q, 2/4-B, 2/4-D and 2/4-A. The platform 2/4-R is connected to several pipelines, and so an assessment needs to be conducted to establish if toppling in place should be delayed or not. Cod 7/11-A has been ranked as 4, so a reef site at Albuskjell 1/6-A could be more beneficial, in terms of transport distance for this structure.

For Alternative 3 (Table 3.6), the platforms decommissioned after 2005 could be placed at the Ekofisk Tank or Ekofisk B/K, depending on the sediment contamination levels at end of production.

For alternative 4, from an environmental (contamination) perspective, this is the most favourable, i.e. the Albuskjell 1/6-A reef site, with all structures decommissioned in 1998-2005, and another reef site at Eldfisk 2/7-B with all structures decommissioned after 2005.

For alternative 5, the Albuskjell reef site has potential as a «cleaner» reef site, than the Centre. However, the Centre, including the Ekofisk B/K has a good potential as a reef site, since most of the structures in phase 2 can be toppled in place.

For Alternative 6, all the structures on the Greater Ekofisk field will be toppled in-place. From an economical viewpoint this is the most favourable alternative. From an environmental viewpoint, this may be not as beneficial as using clustered reefs to optimise the reef habitat and avoid unfavourable sites.

3.4.4.3 *Structures useful for other potential reefs*

Table 3.5, 3.7 and 3.8 above present the different alternatives for reef locations, and ranking of potential structures that are suitable as reef components at the different reef sites. Locations for potential reefs, as described in detail in section 3.3 above, are Albuskjell 1/6-A and Eldfisk 2/7-B.

Obvious, only the platform at the reef site core (the reference point) will be toppled in-place. All other structures will be transported from other locations. The ranking will therefore take into consideration these criteria: toppling or transportation, volume and complexity and weight multiplied by distance.

The two reef core locations may be treated equally in terms of the number of structures that could be moved to the sites. The ranking score shows how suitable each structure is. In general, a jacket with structures scored 2 and 3 is a good suggestion. A structure scored 4, will either have a small volume, or have a high weight*distance number. They are not considered unsuitable, merely less convenient to use.

The average number of jackets to be placed around a core depends on how the reef creation around the Ekofisk Tank will be implemented. If Alternative 1 for the Tank is decided upon, then an alternative reef site will be unnecessary. If Alternative 2 or 3 is decided upon, then the potential reef site suggested for Albuskjell 1/6-A will be unnecessary. The potential reef site Eldfisk 2/7-B will then be a useful alternative.

3.4.4.4 Evaluation of the suitability of non-jacket structures

The criteria for suitability for main structures (section 3.4.3) also applies to the non-jacket structures. In addition to the above mentioned criteria, other criteria discussed in this section are:

- expected lifetime, i.e. supplied with anodes or not;
- weight of the structure, i.e. stability on the seabed;
- size and complexity of the materials on the structure.

The individual volumes of other structures to be used are considerably smaller than the main jacket structures. Their structural complexity is however suitable for use as reef components. All these proposed noon-jacket reef components can be toppled in place or transported relatively easily, because of their small size and weight.

(1) Expected lifetime

The economic lifetimes of these different structures are, in this study, assumed to be the same as those of the main structures. In terms of expected lifetime, some of the structures are considered suitable, especially the flare stacks and the bridge supports, mainly because of their weight and long lifetime, due to the anodes. The expected lifetime is about 150 years (see discussion in section 3.5.5). The structures not supplied with anodes, such as the bridges and drilling towers, will be subjected to corrosion at a fast rate, when placed on the seabed.

The bridges and drilling towers are coated with paint which, to a certain degree, will hinder degradation, but without anodes, the expected lifetime is estimated to be approximately 127 years (Corresist, 1995). The corrosion rate is not a single unique quantity, since it will depend on a number of factors. It will anyway vary significantly with time i.e. seasonal changes and with location.

There is no ranking of these components, but the lifetime of reef component supplied with anodes, i.e. underwater structures, will naturally be longer than the structures in use above the sea surface.

(2) Weight of structures, i.e. stability on the seabed

The expected lifetime, will vary between 100 - 200 years. The cross section of the steel, and also the total weights of some of these other structures, are however substantially less than the main structures. This again implies that they will be more susceptible to the North Sea environment, such as storms and prevailing currents. Their main problem is that their stability is less than the main jacket structures, due to their low weight. This can be solved by toppling or placing the main jacket structures on top of them. This could be a useful solution, especially if the bridges and drilling towers will be used as artificial reef components.

The other problem with these smaller structures is the potential for creating debris. The smaller modules will give little increase in total enclosed reef volume, and will probably also have a shorter lifetime compared with the larger units. They are however included in this report, because of their configuration and possibility to add to the overall volume of an artificial reef.

(3) Size and complexity of the materials on the structures

Suitability is expected to be limited by their relatively small size or the complexity of the materials used in their construction. The topside modules in general are basically not considered useful as artificial reef component, simply because of their content of a wide register of materials not acceptable to the marine environment, and because of their lack of both structural complexity and usable volume. The other structures suggested in this section, will probably have a small contribution to the overall volume, and therefore efficiency, of a reef, due to their size.

The flare stacks and bridge supports may contribute if placed in close proximity to other main structures. The bridges, and drilling towers may sink into the sea-bed, and hence not contribute to the overall reef volume. They could represent a potential for debris accumulation in the future, if not secured, or placed under main structures. Natural forces or fishing equipment may move these structures, with unknown results. These issues are discussed extensively in sections 3.5.5, 4.5.5 and 5.6.4.

(4) Incorporation of other structures into the alternatives

The components presented in Table 3.2, are similar to the associated main structures, with respect to economical lifetime, the proposed reference point and the exact location of the main structure. The exact position of structures used in each Alternative is defined in section 3.6. *Scenarios at Ekoreef* and in Appendix 3.1. *Visualisation of the proposed scenarios.*

As mentioned earlier, the weight and size off all components, and lack of anodes of the bridges and drilling towers, may imply that they should be secured or jackets placed on top of them. This aspect has not yet been investigated, and the idea must be carefully evaluated before implementation. The flare stacks and bridge supports can be placed in close proximity to the reference platform, to add to the reef configuration whether it is for fishing or habitat enhancement purposes (see Section 3.5 *Design of artificial reefs).* The suitability of these non-jacket structures is summarised in Table 3.9.

Table 3.9: *Suitability of non-jacket structures as artificial reef components.*

Component	Suitability	Reason for inclusion/exclusion
Topside modules	No	Difficult to prepare Small usable volume
MSF's	Yes	Large and structurally complex Considered as part of jacket
Flare stacks	No	Too light weight - stability & debris
Bridge supports	No	Too light weight - stability & debris
Bridges	No	Too light weight - stability & debris
Drill towers	No	Too light weight - stability & debris
Flame booms	No	Too light weight - stability & debris
Pipelines	--	Not evaluated in this study

Alternative reef sites and suitable structures suggested for these sites are evaluated in this chapter. The next step will then be to consider the design of reef, using of the information presented in this section.

3.5 Design of artificial reefs

3.5.1 Introduction

Optimal reef constructions and placement of the jackets are dependant on which species of fauna, or flora in more shallow waters, ("target organisms") are desired to live and develop around the reefs. The design of reef configuration are of less importance than the volume and juxta-position of the jackets, in relation to the ability of the reef to attract local fish-species (Stanley & Wilson 1991). This suggestion has not though been quantified for platform reefs.

Even if platforms are toppled rather than transported, some optimisation of the reef configuration may be possible in closely positioned structures that are toppled in pre-defined direction according to a reef design determined prior to toppling of the first structure.

Based on previous reports and previous chapters clustered reef sites are considered the best alternatives for the creation of artificial reefs at the Ekofisk field. Reefs will be created by bringing together various cleaned structures from different locations. In this case the following potential reef sites have been chosen:

- Ekofisk Tank 2/4 -T;
- Albuskjell 1/6-A;
- Eldfisk 2/7-B.

The designs of the reefs, laid out at suitable locations chosen previously in this study, are adjusted to the existing platform operation and proposed cessation dates presented in Table 3.2. This could exclude the most beneficial layouts, because sediment characteristics and contamination from previous drilling operations may still have some, though probably small, negative impacts on the reefs created.

3.5.2 Identification of designs

Reefs at Greater Ekofisk field can be configured in three main ways:

- a straight line of components;
- assembled and placed in blocks or circular patterns;
- units inserted within each other.

3.5.2.1 A straight line

The straight line approach may have several advantages:

- linking with other distant structures;
- optimal position with respect to currents, i.e. perpendicular to the prevailing flow from the north-west;
- high surface area : volume ratio;
- easy access for fishing activities;
- components in the reef can create a variation by using different volume (i.e. size) of the jackets, and placing the jackets in various distance from each other;
- potential for safer trawling around the reef margins.

An example of a reef designed in a straight line is presented in Figure 3.15. The disadvantage of such a design is that it will be less suitable for habitat protection due to the ease of access, and the reef will be spread over a greater distance and hence may hinder off-reef fishing activity.

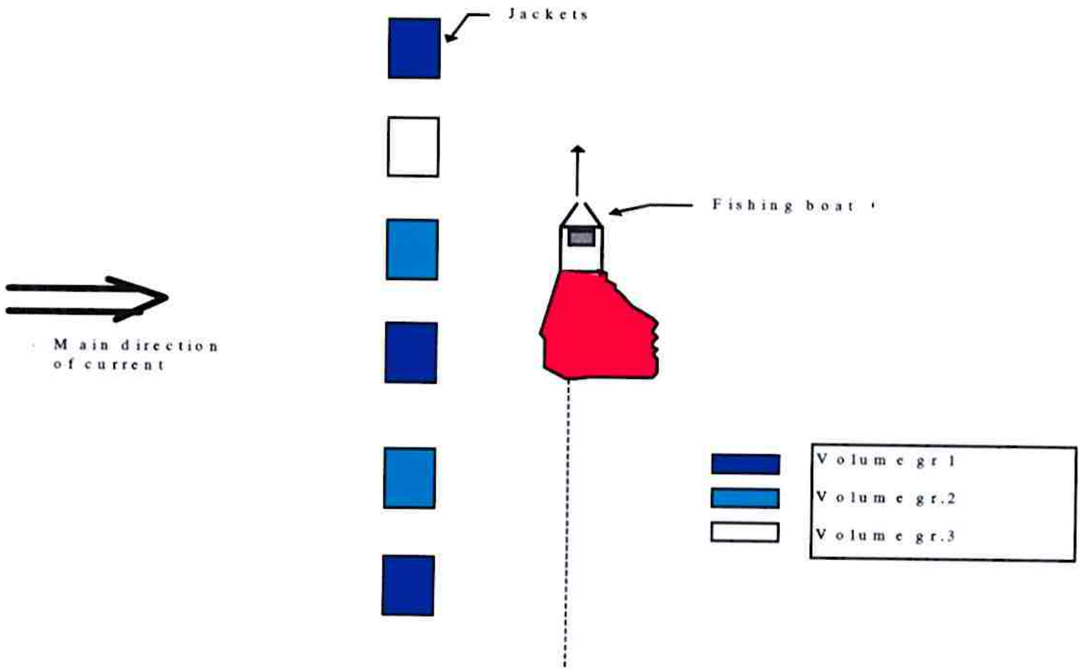

Figure 3.15: *Possible design of a linear reef. Jackets may have different volumes and spacing distances. The line of jackets is placed perpendicular to the prevailing currents.*

3.5.2.2 Circular or block formation

The assembling a clustered reef in blocks or in circular patterns can be a means of protecting habitat or fish, both from fishing pressure or natural predation. The main difference between a reef placed in a block formation or in a circular pattern are their juxta-position. To simplify the reef identification, a circular pattern is discussed here. A circular reef should be designed so migration between the jackets is possible, but the sphere of influence should not overlap so much that competition reduces the standing stock or potential overall volume is reduced. A circular reef will contain different sized jackets. Variation in their volume and complexity may even create more habitat niches. A circular reef is shown in Figure 3.16.

By restricting fishing access to the reef by virtue of the circular shape, the protected zone can be made far larger than merely the volume of the jackets themselves. Such a reef would be difficult to fish using trawling gear, and drifting of a seine net inside the complex would make the use of nets risky. Whilst long-line fishing would be possible, fishing close to a circular reef would be difficult and even risky. As habitat protection is the main aim of this design of reef, this is therefore considered advantageous.

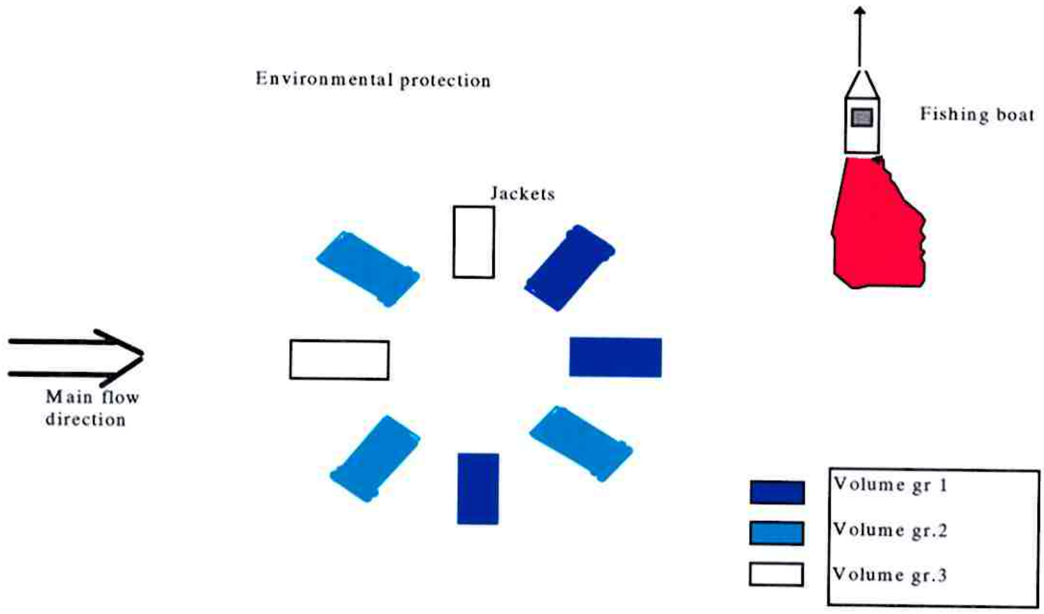

Figure 3.16: *Example design of a circular reef. Jackets may have different volumes and spacing distances.*

3.5.2.3 Components inserted within each other

To increase the infrastructure, it may be possible to insert units within each other. This may increase the niches available within a structure. Insertion could basically be used to increase the internal complexity. In this report an insertion will not be considered, since the jackets are assumed to be complex enough. Also insertion will make the design implementation more complex than necessary.

3.5.3 Criteria for suitable designs

Information is limited in this respect, since no planned platform reefs have to date been built in the North sea. Most of the information about optimal reef layouts has been gained by examination of small structures. Little knowledge exists regarding the effects of large structures, such as platform jackets at the Ekofisk field.

The average jacket in the Ekofisk area has a volume of about 150 000 m^3. This volume exceeds anything that has been evaluated or tested in Europe or the USA to date (Cripps *et al.*, 1995). Some information about optimal structures from Japan and the Gulf of Mexico, are however noted here.

The following design criteria will be discussed:

- orientation, i.e. compass direction of reef;
- juxta-position of jackets within reef;
- number of jackets at the reef;
- distance between jackets in the reef.

These criteria will naturally incorporate the considerations and decisions made for suitable locations and suitable structures. Again, it is important to state that the decisions made from point to point are based on several defined assumptions and limitations, which are extensively explained in the introduction section (2.2).

3.5.3.1 Orientation, i.e. compass direction of reef

Other important factors in creating the most effective artificial reefs include having steep reef sides and large structural complexity. If possible the reef units should be placed perpendicular to general prevailing currents. This will locally increase the water flow, makes zones of more stagnant water inside the reef unit, and accentuate any internal wave and low frequency sound that would be produces by the reef. All these characteristics would enhance the potential attractiveness of the reef to fish (Stephan *et al.*, 1990). Orientation may not though be as important a factor as complexity, volume or distance from neighbouring structures. More work is required to determine this.

3.5.3.2 Juxta-position of jackets within a reef

The definition of reef juxta-position is: the position and orientation of a reef component structure in relation to other reef components. Juxta-position may, in many of the alternatives presented later, be the most important design criteria. The position and compass direction of each jacket may decide whether the reef is created for habitat protection or fishing issues.

3.5.3.3 Number of jackets at the reef

As described in the previous section, several structures will have potential as reef components. The total volume of a reef will depend on the number of jackets used, and hence the potential ability to attract and retain fish on the reef, or to protect them. Also reef configuration and different alternatives will be substantially influenced by the number of jackets placed at a reef. Generally, the greater the number of jackets, and hence volume, incorporated into a reef, the greater the effect on fish attraction or habitat development would be expected.

3.5.3.4 Distance between jackets in the reef

To maximise reef efficiency, single reef components should not have extensive overlap between zones of increased fish densities. This implies that the components should be placed at a distance of about 50 - 200 m from each other, depending on the extension and complexity of the single structures (Bohnsack & Sutherland, 1985).

The spacing between the jackets at the reef will be a compromise between two considerations:

- the desire to maximise the potential of the reef effect by having the individual zones of effect around each jacket touching but not overlapping or duplicating to any great extent;
- the desire to minimise the gaps between jackets to discourage the use of mobile fishing gear around the jackets, to the detriment of the long-term usefulness of the reef.

The zones of effect around each jacket will be unlikely to extend beyond 100 m. The width of typical trawl gear is 20 - 30 m. A safety zone will need to be established around each potential reef, and this will imply no fishing will be permitted through the reef, irrespective of if it is to be used for habitat protection or enhanced fishing. A fishing reef will though be designed so that fishing can be conducted around the margins.

3.5.4 Evaluation of suitable designs

Suitable designs for the Ekoreef will depend on the use to which the reef is put. As stated previously, there are two main uses of interest; environmental protection and fishing enhancement. Other perspectives are outside the scope of this study.

From an environmental perspective, a reef with a circular pattern may optimise the environmental protection, both in regards to fishing pressure and habitat enhancement. From a fishing perspective, a reef in a straight line may optimise the potential for fishing. In the following *Scenarios* section, optimal designs for both habitat protection and fishing will be presented. The management of reefs for protection or enhancement is discussed in detail in Report 5, *Management.*

3.5.4.1 Fishing

Several aspects need to be considered in a discussion of the design of reefs for fishing purposes. These include catch sizes, fishing effort, management, catch species, fishing gear and methods.

Evidence to-date suggests that the existing working platforms are having a small, beneficial effect on local fish populations. The extent to which these habitats are having any long-term, or significant effects on the total populations of these species will only be gauged when the temporal utilisation of platforms by fish and their possible movement between platforms is more fully examined. It is clear, however, that a reef effect can be created around North Sea oil platforms that influences the behaviour of commercially important species.

The behaviour and location of fish on the reef will influence how easy they are to catch, and hence influence the reef design. The optimum situation from a fisherman's perspective would be to have the saleable fish in dense schools standing off a short distance from the reef edge.

Several methods are available for fishing around artificial reefs, such as mid-water trawls, bottom trawl, Danish seining, and long lines. The choice of gear to be used around an artificial reef may need to be modified. Providing the exact location of reef is known, such as by use of sonar, it should be possible for fishermen who are skilled at working in various weather and current conditions, to trawl close to the reef. Seines and trawls may therefore be used around a reef to catch the larger near-reef fish, but will be unsuitable for use close to or within the reef. Long-lines may be possible to use closer to the reef.

Variations to the efficiency of these different methods will occur, and are only possible to document after fishing at reef has been conducted by commercial fishermen. Only the area to the east of the Ekofisk is suitable for bottom trawling, other areas around Ekofisk are not suitable because of the bottom type. The reef exclusion zone for seine netting would be smaller than for trawling, because the gear can safely be used closer to the installation. Manoeuvrability off a fishing boat during fishing with a seine net is though negligible, so account must be taken of local conditions (Anon, 1993)

Artificial reefs primarily redistribute existing fish, but they can still be useful as fisheries management tools for increasing catchability, making fish easier to locate. They can also retain highly migratory species in the local area (Bohnsack *et al.* 1991).

Even when the production at the field has ceased, and reef components are well established in place, there may be a continued problem with the drill cutting piles and pipelines scattered over the sea-bed.

Fishing techniques may need to be re-evaluated, especially as trawling around at the Ekofisk field could be a risk. Trawling over drill cutting piles should be avoided, since this could either rip the trawl, or in worst case disperse the contaminated piles over a greater area. The use of a trawl to break up and disperse a pile was however unsuccessful because of the hardened crust developed over the pile. Trawling may then not have as great an effect on pile resuspension as may be envisaged.

In summary, artificial reefs at the Ekofisk field can be used to create fishing opportunities, reduce user conflicts, save time and fuel, reduce fishing effort, make locating fish more predictable and increase fish abundance at deployment sites by attracting dispersed fish and producing new fish biomass. Fishing quota will still be enforced, so over-catching should not be a problem.

There will be a beneficial effect on the fishery, primarily in terms of the socio-economics of the fishermen. This will be irrespective of an increase in fish stock. Since the reefs are expected to attract fish, then the fishing effort may be reduced. In terms of socio-economic impacts, this imply a more secure activity for both the fisherman, and the processing industry, and hence potentially also the market. This will be discussed extensively in Report 5, *Management*.

3.5.4.2 Habitat protection

Environmental or habitat protection refers to the protection of the whole environment, which can include spawning grounds, food sources, juveniles of harvestable species, harvestable fish, shrimp or shellfish, protection and mitigation of degraded habitats, and protection against currents and predation for juveniles. Primarily a habitat protection reef restricts access and the resulting negative impacts of commercial fishing.

A wide variety of environmental cues are thought to play an important role in attracting fish to artificial reef components, including current patterns, shadows, species interactions, sound, touch, pressure and visual cues of size, shape, colour and light (Bohnsack & Sutherland 1985). An artificial reef can be important for the fish stock of a much larger area then the reef itself, because its gives protection to the fish at their most vulnerable stages (Anderson *et al.,* 1989).

Overall, artificial reefs are thought to aggregate existing scattered individuals and allow secondary biomass production by (Bohnsack & Sutherland, 1985; FAO, 1990):

- increasing survival and growth of larvae and juveniles by providing a settlement substrate, shelter from predation and additional food resources;
- creating new food webs through the provision of new spaces, habitats and colonisation patterns;
- protecting the sea-bed and nursery grounds;
- recycling energy by retaining a localised ecosystem.

It would therefore appear that the immediate platform environment is one which fish find acceptable and to which they are attracted. They may find extra food there, shelter from currents, and a reference point for efficient station-keeping. Within a 500 m safety zone they will also escape fishing pressure. The structures scattered throughout the North Sea therefore provide local 'reef habitats' utilised by fish for a time (Aabel et al., 1997).

The greater Ekofisk field could become an important conservation site for North Sea fish species. The central part of the North Sea, where Ekofisk is located, is a spawning area for mackerel, cod and haddock, also some spawning activity has been recorded for whiting

(*Trisopterus luscus*) and sole (*Solea solea*) (see Report 2, *Current status*; Daan *et al.*, 1990). The spawning biomass for many North Sea fish is within safe biological limits, except for herring (*Clupea harengus*), plaice, cod and mackerel. The standing stock of commercially caught fish in the southern part of the Norwegian sector in the North Sea is currently weak due too excessive fishing pressure. One solution to this is to create a reef that functions as a sheltered nursery ground for young fish, allowing more individuals to pass through the high mortality juvenile stages than normal (Cripps *et al.*, 1996).

3.5.5 Environmental impact of reef design

The effect of attracting and concentrating various species of fish is primarily promoted by the physical presence of the jacket structure. The environmental impact in this respect can be defined as how the environment changed from before to after the creation of the reef. In Report 4, *Impacts* the environmental impact after the creation and physical presence of an artificial reef will be discussed in detail.

Potential sources of environmental impact during artificial reef establishment include:

- energy use and air emissions during reef implementation;
- the physical disturbance of the sea bed under toppling or removal operations;
- the physical presence of the structure on the sea bed.

These three environmental impacts will be discussed in the following sections.

3.5.5.1 Energy use and air emissions during reef implementation

The energy use and emission discharges during the reef implementation aspects deserving consideration. Calculations of such matters are however extremely uncertain since numerous assumptions and factors need to be stated prior any calculation. From an environmental perspective, the less energy consumed and the less emissions to air discharged, the better. This must though be seen in the context of an overall evaluation of Alternatives 1-6.

In Appendix 3.2 *Calculations for energy use and air emissions*, the values are calculated and summarised in Table 3.10.

Table 3.10 indicates that both energy use and air emissions are least for Alternative 6, since this Alternative only comprises toppling *in situ*. Alternative 1 has less energy use and air emissions than Alternatives 2, 3, 4, and 5. This will be discussed in a wider context in Report 4 *Impacts*.

***Table 3.10**: Summary of energy use and emissions predictions (from Appendix 3.2).*

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6
Total energy use (GJ)	212,388	274,390	265,806	307,525	290,082	174,432
Total air emissions (t)	25,763	32,930	32,513	36,155	34,750	22,821

3.5.5.2 Physical disturbance of the sea bed during toppling or removal operations

During the 2/4G jacket removal operations or toppling *in situ*, there may potentially be re-suspension of sediments, and hence toxic material. By disturbing the seabed, fine particulate sediments will resettle slowly. Because fine particle sediments will resettle slowly, they will tend to concentrate at the sediment-water interface. Much of the toxic substances will be adsorbed to fine sediments particles, but some may be liberated in soluble form and taken up by the planktonic stages of fish. Consequently, any such attached toxic materials will also tend to concentrate at the sediment-water surface where they will be in close proximity to benthic organisms and demersal fish and thus, probably more available to biological uptake than if they had remained buried on the sediment.

The re-suspended material will contain certain amounts of hydrocarbons that may cause adverse effects on marine organisms. The re-suspended particles will however be dispersed by ambient sea water due to turbulent entrainment and oceanic dispersion, so the concentration of the re-suspended material will naturally decline with distance from the removal site.

Offshore operations associated with the toppling or removal operations, including vessel activity and accidental spillage of residual chemicals, would probably have negligible long-term effects on pelagic and demersal species living in the vicinity of a structure (AURIS 1995). There is though a possibility that the toppling or removal operations themselves could disturb fish in the immediate area.

3.5.5.3 Physical presence of the structure on the seabed

A structure laying on the bottom will alter the physical environment in the area. These effects can be minimised or maximised depending on the configuration of the structure. New local currents and flow patterns will be created around the new reef. The influence on the bottom current will create sedimentation zones where organic and inorganic particles can settle. This can create oxygen depletion if the organic matter content of the sedimentation is great. Since the jackets used are of an open structure, the sedimentation will probably be of little concern, prior to the collapse of the structures (see section *3.5.6*).

A jacket can be expected to disrupt the flow of water by its physical presence, so providing shelter from the main force of water flow. Eddies will be created as the water current passes through the lattice structure. These areas of shelter and swirling movement may serve to give the fish a bioenergetic advantage when they are in areas of shelter, because they do not use so much energy to swim, or they obtain a feeding advantage if prey species are disoriented or concentrated by the swirling water.

For the purpose of this section, a preliminary qualitative assessment of the potential impacts associated with the physical presence of the structure in the marine environment and its subsequent interference with other legitimate users is presented in Table 3.11 below. A fuller review of the impacts is presented in Report 4: *Impacts*. Impacts associated with structural degradation will be discussed in the following section.

***Table 3.11**: Preliminary assessment of the potential impacts associated with the physical presence of the structure (Source: Dames & Moore, 1996).*

Potential non-beneficial impacts	Potential beneficial impacts
The Physical presence of the structure will result in smothering and destruction of benthic community immediately under it. The area occupied will be in part dependent on the method of disposal employed, but will be at least equivalent to the area covered by the structure. Paints & coatings used for corrosion protection for the splash zone and topsides may inhibit or at least retard the rate of colonisation.	The structure may introduce a solid substrate into and otherwise uniform soft sediment area that is suitable for colonisation by biota, and could lead to a localised rise in biodiversity..
The physical presence of the structure could exclude commercial fishing from an area. This exclusion may encompass a new area, or constitute the continuation of exclusion from an existing exclusion zone. Fish, caught in the vicinity of the installation could be tainted, or contaminated by residues remaining adhered to the disposed structure.	The structure may act as a fish aggregating device thereby acting as a fisheries management tool. The result could be a reduction in fishing effort as a result of the structure providing a predictable location for fish stocks. The structure may also provide shelter for earlier life stages thus enhancing recruitment.
The structure may interfere with navigation. However, there is a statutory requirement to allow a clear water of 55m clearance above a disposed structure (unless defined as an alternative use, e.g. reef), and to inform the relevant authorities of its exact location and aspect and to provide, monitor and maintain navigation aids at the installation.	
The structure may generate debris, or in the case of concrete, leave reinforcing steel exposed as the concrete breaks off, which may be transported to areas away from the disposal site. Therefore there is a requirement to monitor the site after disposal. Also there may be potential residual liabilities from claims for damage to fishing gear.	
Loss of material with re-use/re-sale potential for recycling especially materials of construction (bulks). Potential net cost should be based on assessment of energy cost to manufacture new material from raw materials balanced against removal costs including transport, rendering and recycling costs etc.	Materials, systems and equipment for which interested parties can be identified should be removed prior to sea disposal

It is expected that the structures will be in sufficient water depth, and have a sufficient weight, to resist all anticipated wave and current forces and thus remain stable on the seabed. Assuming the jackets are placed horizontally, anchors may be used to fix the structure to the seabed as added protection to ensure that they do not roll over, or move from the site (Aabel *et al.,* 1997). As they degrade however, the effect of the reef's presence on the seabed over a long period may become reduced, until the structure itself disappears.

If the structures, and sediments on which the reef are placed, are properly decontaminated prior to reef creation, few negative impacts on the biological community would be expected from the reef. Some leaching of metals will occur when the structures are deteriorating, but negative effects should be expected to be negligible (Cripps *et al.,* 1995). Iron is the main component of the steel jacket, and this will be deposited and dissolved as the structure starts to deteriorate. Iron is not considered to be a harmful substance, and can in some instances be considered beneficial to the biological community, because it can be a growth limiting nutrient in marine ecosystems.

3.5.6 Degradation over time of the reef structure

3.5.6.1 Subsidence

Subsidence in the area of Ekofisk field is understood to be approximately 35 cm per year. This movement may increase the risk of structural instability and break-up of the placed jacket structures. Risk assessment in this regard is outside the scope of this work, but may need to be conducted at a later date.

The water depth in the Greater Ekofisk area is currently about 70 - 80 m. In the central Ekofisk complex, the depth is at present 76 m, but this is expected to increase to 90 m by 2040 (Cripps *et al.,* 1995). Reef components may degrade faster, and be made more unstable because of the subsidence. This effect may however be minor in comparison with the degradation of the structures once the corrosion takes place and the anodes are exhausted.

3.5.6.2 The potential for the creation of debris

Four factors will influence the rate at which debris is created from material or structures placed at sea, and the likelihood that it would interfere with users of the sea. They are:

1. the rate at which materials, particular steel, will disintegrate;
2. the potential for pieces of a structure to be moved across the seabed by natural forces;
3. the potential for pieces of a structure to be moved across the seabed as a result of interactions with fishing gear, anchors, or other equipment towed by a surface vessel;
4. the likelihood that pieces of a structure, at an unmarked location, will be snagged by fishing gear.

In the following sections, some of the data relating to these topics is examined and attempts are made to assess the likely impact of debris on other users of the sea.

3.5.6.3 Structure disintegration

The structures, when placed on the sea floor as reef components, are expected to be robust and have a reasonably good integrity. There are 24 platforms that will be available for use as artificial reef components. They are all considered stable structures when placed on the sea-bed, with an expected lifetime of over 150 years (Kjeilen *et al.,* 1995). If only the steel frame remains, the corrosion and final collapse of the structures will depend solely on the deterioration of the steel itself.

Aluminium is found in substantial quantities in anodes and, if a disposal at sea option is chosen, would be released slowly through anode dissolution. Aluminium has no biological role, is not involved in any biological cycling because it is not ready bio-available, and is thus considered relatively non-toxic.

How the structure degrades and how potential debris from a collapsed structure impacts the environment are important issues to consider. As already mentioned, the steel-structure will be subjected to corrosion. The degradation of the structure can be divided in two phases: the protected phase and the free corrosion phase

(1) Protection phase

From previous studies(Corresist AS., 1995), it is estimated that the protection phase will last about 35 years. This is based on the anode consumption rate on a structure. During the free corrosion phase the anodes will be entirely consumed, and the structure will deteriorate as a result of natural seawater corrosion.

(2) Free corrosion phase

The corrosion rate is not a single unique value, since it will depend on a number of factors. In particular, the corrosion rate will vary significantly with time, i.e. seasonal changes, and with location. Studies have estimated (Corresist AS., 1995) that the free corrosion phase will be about 127 years. Total Functional Lifetime (TFL) is calculated by adding the times of the protected and free corrosion phases. This functional lifetime should also be expressed as a probability function. Based on this probability function, Corresist AS (1995) has estimated that there is approximately a 65 % chance that the structure will be able to function as a reef for a period exceeding 135 years and a 35 % chance that it will last more than 168 years. The TFL is expected to be approximately 162 years (Corresist AS., 1995).

(3) Time for collapse and potential for debris

An SLP study (1994) has shown that collapse mainly occurs due to strength overloading (buckling or rupture) in storm conditions after more than 75 % of the effective cross section members have corroded away (SLP, 1994). In a study performed by Corresist AS (1995), the collapse of the supporting members will occur when 80 % of their nominal wall have corroded away in a large enough area. At this time they will no longer be capable of supporting the weight of the main legs, and that the structure will consequently collapse and cease to function as an upstanding reef.

The debris from a structure used as a reef is most likely to occur after the structure has collapsed. Based on this, the collapse may occur after about 127 years (Corresist As 1995). The protection phase is 35 years. The free corrosion phase before collapse is 75 - 80 % of the 127 years, which gives about 100 years. Add the protection phase (35 years) with free corrosion phase before collapse (100 years). This gives approximately 135 years before collapse of the reef, and potential debris problems.

If structures which are not supplied with anodes, like bridges and drilling towers are used as reef components however, there will be no protection phase to consider. These structures can therefore collapse after approximately 100 years. Maximum lifetime expectation is 168 years, and time for reef collapse of the structures without anodes is 100 years. This gives 68 years of potential debris from the reef. This implies that there may be a potential for debris on the seabed for at least 60-70 years, before the reef structure more or less has disappeared.

3.5.6.4 Potential for structures to be moved by natural forces

A joint industry study (SLP, 1994) examined the potential for items of debris and parts of structures to be moved across the seabed by waves and currents. The study concluded that only light cylindrical members, with no protrusion, and lying on a hard, compacted sediment, were likely to be rolled across the seabed. The track and distance could not be predicted with accuracy, nor could the cumulative or net excursion path from the original site of deposition be predicted.

Only the largest components have been chosen for reef creation, to avoid the risk of debris migration due to bottom currents. Although eventual disintegration is inevitable, structural failure may not result in separation and hence may not result in the generation of mobile debris items (AURIS 1995). However, the opposite may be the most likely to occur, i.e. generation of mobile debris items. In addition, because corrosion will continue after the structure failure (collapse), a failure occurring towards the end of the corrosion life of the cross section will mean that any potentially mobile debris that is generated will have a limited life, because the remainder has already corroded away (SLP 1994).

Several factors would act to reduce the likelihood of movement of objects on the seabed. These include obstructions on the seabed itself, burial of the structure into the seabed as it disintegrate, the presence of protrusions on the object, and interaction with other debris in close proximity, which might restrict movement (AURIS, 1995). These issues are also discussed in section 3.3.2.3 *Possible flow and scour features*, and section 3.3.2.4. *Flows through a platform reef.*

3.5.6.5 Potential for structures to be moved by fishing vessels

The continued presence of structures on the seabed may represent a long-term liability for the owner of the platform. Over time the structure will corrode and hence the debris could become a snagging threat to fishermen. There may be a risk of sea floor debris, from deteriorating toppled structures, even though reef components should be prepared in a such way as to remove all components that may deteriorate fast. It is important to stress that structures in artificial reefs are placed on the seabed at a defined location, so the spreading of sea-floor debris could be minimised by careful placement. Only if placement has been adequately planned can jackets be considered as suitable artificial reef components.

Even if the reef structure itself is correctly located and properly marked, the long-term effect of leaving a structure on the seabed will still be of concern. In particular, the collapse of the structures, and the possibility of debris damaging a fishing trawl. The ability of fishing vessels to move snagged items depends on three factors (AURIS, 1995):

- the weight of the object;
- the extent to which it may be stuck in the sediment;
- the pulling force of the fishing vessel.

The potential for debris to be encountered by fishing vessels is a function of:

- the type of gear used,
- the numbers of hours fished;
- the size of the debris objects;
- the number of objects;

- the location of the object
- the clarity with which the debris is marked both on-site and on nautical maps..

The fishing gears most likely to snag debris are bottom trawls or beam trawl, that are towed along the seabed for several kilometres.

As discussed above, the debris from a collapsed reef may actually be somewhat limited. The main aspects that may limit the potential debris from an artificial reef are:

1. The structures used as components have a weight and size that limits creation of any debris before the total collapse of the structure.
2. The jacket are toppled over and anchors are used to fix the structure to the seabed.
3. Several factors would act to reduce the likelihood for movement of objects on the seabed. These include obstructions on the seabed itself, burial of the structure into the seabed as it disintegrate, protrusions on the objects that would dig into the sea-floor, and interaction with other debris in close proximity..

Based on the information provided above, there are indications that debris could potential become a problem at a reef site. The quantity and extent of the debris will be highly dependant on the choice of reef configuration Alternative (1-6) selected. It is also expected (though indications are based on little or no hard data) that the spread of debris from a collapsed reef may actually be limited in extent.

Should the creation and extent of debris resulting from reef creation be prioritised as a major reef design issue, then Alternatives that minimise debris transport may need to be chosen. Providing that the area around a collapsed reef continues to be adequately marked, as it would have been during the lifetime of the reef, then it may be considered that it is better to have a limited area with much debris, than a large area with dispersed items.

The structures of greatest concern in this respect are pipelines, because their large spans and broken pipe ends could snag fishing gear and pose a threat to vessels and fishermen over a wide area. It is difficult to predict how quickly pipes will degrade and at what locations broken ends of pipes may be created. It is therefore at present difficult to estimate with any degree of certainty the likely level of interaction between fishing gear and pipelines.

3.6 Scenarios at Ekoreef

3.6.1 Introduction

In this scenario description, the artificial reefs at the Ekofisk Tank and other potential reef sites are presented. The description draws together locations, structures and designs to give a full overview of each Alternative. The description will serve as a guideline for further work, in terms of specific implementation of reefs at any location.

Again, to avoid a complex scenario description, this section uses all the assumptions, criteria, evaluation and arguments from previous chapters. If other scenarios for either the Tank or other artificial reefs are suggested, the assumptions and priority in the criteria may alter substantially, and hence the arguments stated will change considerably.

As previous sections have indicated, this study focuses on the environmental perspective of artificial reef creation at the Greater Ekofisk field. Scenarios will discuss reefs designed to fulfil either of the two main stated aims: for habitat / fish stock protection; or for enhanced fishing. As stated above, from an environmental perspective, a reef with a circular pattern would be expected to be particularly suitable for habitat protection. From a fishery perspective a reef in a straight line may be suitable for fishing effort.

There have been various studies into the form of and optimal reef for different aims and under different conditions. Stanley & Wilson (1991) concluded that optimal reef construction and placement of reef components will be dependant on the target species. Also, as mentioned previously, volume and juxta-position is likely to be more important than the design of a structure itself.

The scenarios for establishing the four alternatives will be presented in the same format as described in section 3.4.4, *Evaluation of suitable structures*. The six main Alternatives, resulting in a total of 11 scenarios, are and presented in Table 3.12 and Appendix 3.1.

***Table 3.12**: Summary of toppled and transported platforms for all Alternatives. Phase 1, platforms decommissioned in 1998-2005. Phase 2, platforms decommissioned after2005. Yes = platform is toppled. No = platform is not toppled, i.e. transported*

Name	Synonym	Economic Lifetime	Alternative 1 Centre	Alternative 2 Tank. Eldfisk	Alternative 3 Centre. Tank	Alternative 4 Albuskjell. Eldfisk	Alternative 5 Albuskjell. Tank	Alternative 6 *In situ*
"2/4-R"		1998	yes	yes,	yes,	no	no	yes
"2/4-S"	(Statoil)	1998	yes	yes	yes	no	no	yes
"2/4-P"		1998	yes	yes	yes	no	no	yes
"2/4-G"	(Amoco)	1998	yes	yes	yes	no	no	yes
"2/4-FTP"		2005	yes	no	no	no	no	yes
"2/4-Q"		2005	yes	yes	yes	no	no	yes
2/4-B	"EKOFISK B"	2005	yes	yes	yes	no	no	yes
7/11-A	"COD"	1997	no	no	no	no	no	yes
1/6-A	"ALBUSKJELL	1998	no	no	no	yes	yes	yes
2/4-F	"ALBUSKJELL	1998	no	no	no	no	no	yes
2/7-C	"EDDA"	1998	no	no	no	no	no	yes
2/4-D	"VEST	1998	no	no	no	no	no	yes
2/4-A	"EKOFISK A"	2005	no	no	no	no	no	yes
2/4-C	"EKOFISK C"	2009	yes	no	yes	no	yes	yes
2/4-K	"EKOFISK K"	2012	yes	no	yes	no	yes	yes
2/4-W	"EKOFISK W"	2012	yes	no	yes	no	yes	yes
"2/4-H"		2028	yes	no	yes	no	yes	yes
2/4-J	"EKOFISK J"	2028	yes	no	yes	no	yes	yes
2/4-X	"EKOFISK X"	2028	yes	no	yes	no	yes	yes
2/4-E	"TOR"	2011	no	no	no	no	no	yes
2/7-A	"ELDFISK A"	2016	no	no	no	no	no	yes
2/7-B	"ELDFISK B"	2016	no	yes	no	yes	no	yes
"2/7-FTP"		2016	no	no	no	no	no	yes
2/7-D	"EMBLA"	2016	no	no	no	no	no	yes
Number of alternatives			2 (p and f)	2 (p and f)	2 (p and f)	2 (p and f)	2 (p and f)	1
	Sum toppled		13	7	12	2	7	24
	Sum Transported		11	17	12	22	17	0
	Total platforms		24	24	24	24	24	24

3.6.2 Identification of optimal reef scenarios

3.6.2.1 Fishing reefs

Reefs created to assist fishing should be designed so that they have no hindrances to fishing activity. At Ekofisk such hindrances that would wish to be avoided would include pipelines and rock ridges (made for protection of pipelines), contamination and old drill cutting piles from a removed platform, or location of a reef core, i.e. bottom topography in the area. The optimal scenario would then seek to take into account the following parameters:

- minimise hindrances;
- comprise structures with a large volume and complexity;
- preferably be built by toppling as many jackets in-place as possible
- jackets would be available any time at the end of their economic lifetime.

Unfortunately, these criteria are influenced by several variables as presented and discussed earlier in this study. Both for the sake of simplicity and practicality, the optimal scenario discussion need only to consider the following four criteria for suitable designs:

1. orientation;
2. juxta-position of jackets within reef;
3. number of jackets at the reef;
4. distance between jackets in the reef.

Based on these criteria, Figure 3.17 shows how an optimal reef may look like. This optimal reef with few or several jackets in a straight line may serve as a suitable reef design to assist and enhance fishing operations. Whilst assistance for fishermen is the main aim, extend, the reef will also act to enhance fish stock and provide a habitat for epifauna (animals attached to the reef structure).

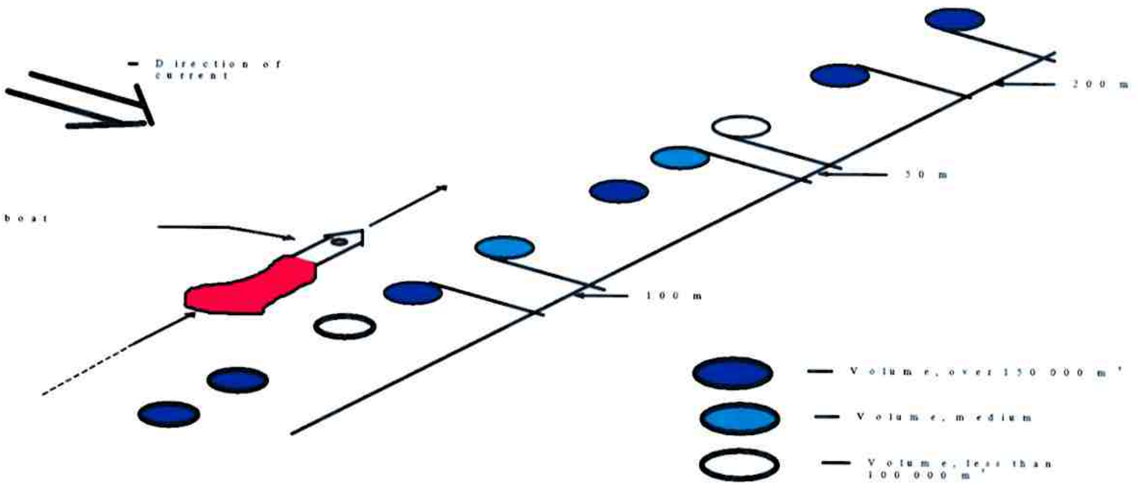

***Figure 3.17**: Example of an optimal reef to enhance fishing. The reef may consist of few to several jackets in a straight line, with distance varying from 50-200 m from each other.*

The prevailing flow form north-west (North Sea Task Force 1993) at Ekofisk through the jackets, and hence the reef, would preferably be perpendicular to the axis of the reef. This flow will create eddies and habitat that would be exploited by several species. To create some variability in current patterns and habitat, the jacket sizes may be varied along the reef axis.

Any change in compass bearing for some jackets, may create a curve in the reef. This will probably not change the reef efficiency, but may increase the risk and difficulty for an operating fishing vessel especially if it is using a mid-water or bottom trawl.

In general, it is preferable that all of jackets should be orientated so that their long axis is parallel with the long axis of the linear reef complex, and if possible, perpendicular to the prevailing currents.

The number of jackets comprising a linear reef will probably be positively correlated with the attractiveness of the reef to fish, and hence also the quantity of fish caught at the reef. The reef may therefore have a certain minimum size, below which fishing will be only marginally enhanced or not effected at all. There is no data available to permit an estimation of this effect, if it exists at all. For the purposes of this linear reef scenario description, it is intuitively proposed that a reef containing more than 5 - 6 jackets may be beneficial.

Distance between each jacket has been suggested to be 50 - 200 m. This is based on published accounts of a region of influence on the fish stocks which extends out 100 m from an artificial reef. To create some variability at the reef, both in terms of current patterns and habitat differences, the distance may vary. This, together with different sizes of jackets next to each other, may create a beneficial (to the fish), diverse range of attractive habitats, without altering the main aim of enhanced fishing.

In effect, this is the marine version of hedgerows issue in which hedges, though small in area can form a valuable habitat and protected pathway between open fields. This will be discussed in more detail in Report 5, *Management*.

3.6.2.2 Reefs for environmental / habitat protection

Reefs created to protect habitat should be designed so that they are both a hindrances to fishing activity and are attractive to fish. Hindrances such as pipelines and rock ridges could be incorporated into such a reef, though care would need to be taken to avoiding damaging operational pipelines.

As with fishing reefs, contamination and old drill cutting piles from a removed platform, or located at a reef core should preferably be avoided, though their deleterious effect is unlikely to be great in the long-term. The optimal scenario would then seek to take into account the following parameters:

- maximise, but limit the extent of hindrances;
- comprise structures with a large volume and complexity;
- preferably be built by toppling as many jackets in-place as possible
- jackets would be available any time at the end of their economic lifetime.

Unfortunately, these criteria are influenced by several variables as presented and discussed earlier in this study.

Both for the sake of simplicity and practicality, the optimal scenario discussion need only to consider the following four criteria for suitable designs:

1. orientation;
2. juxta-position of jackets within reef;
3. number of jackets at the reef;
4. distance between jackets in the reef.

Based on these criteria, Figure 3.18 shows how a habitat enhancement reef may look. These reefs with 5 - 8 jackets or more may serve as a reef units. Other reef units may be placed in close proximity to build up a complex of protected habitats.

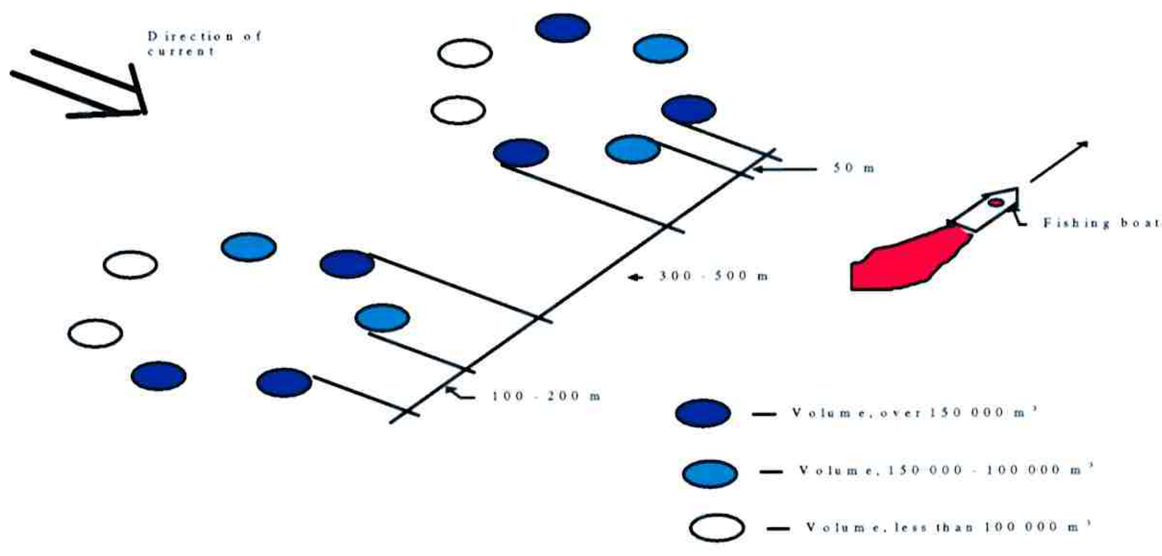

Figure 3.18. *An optimal reef for environmental protection. The reef unit consist of 5 - 8 jackets, with a distance of 50 - 200 m between each other. The distance to the next unit may be set to 500 m to enhance migration and community diversity.*

Smaller jackets with less volume can be placed up-stream of the larger jackets so that the flow through the reef is optimised. The juxta-position is designed so that juveniles may find protection in-between the jackets, but may also be able to migrate, under protection, from one jacket to another. The juxta-position also enhances the shade, provides changes in flow pattern and area for the potential inhabitants. The inner circular clear zone creates an open area in which fish may live off-reef, but relatively protected from commercial fishing. In this way, a diverse fish community may develop in protection.

The lowest numbers of structures to create a circular pattern, is about four jackets. To close in or broaden the circle of jackets, may change the habitat considerably. If the circle becomes too large, the protective nature of the reef may be reduced because the clear zone in the middle becomes too exposed, both in terms of protection for juveniles or fishing pressure. Conversely, if the circle contains only three or four jackets, the reef may not be adequately enclosed, thus not conferring an adequate level of habitat protection.

Distance between jackets in a reef unit, may depend on number of jackets in the unit. Generally a jacket, as stated above is expected to influence fish populations out 100 m from the artificial reef structure. This implies that a distance of 50 - 200 m between the jackets may be optimal (Bohnsack & Sutherland 1985).

Another distance to consider is that between reef units. Placing some reef units in a configuration shown in the example in Figure 3.18 may create an exchange and migration of different species, and therefore increase the community diversity. This distance between units may not exceed 500 m. There is though no published information on which to base an estimate of the optimum distance between platform units in the North Sea.

3.6.3 Scenarios at the Greater Ekofisk field

3.6.3.1 Scenarios for Alternative 1: (Centre)

The reef creation can be implemented using structures as they become available until all of the platforms are decommissioned, after 2028. 13 jackets can be toppled in place and 11 jackets will be placed in a complex reef at the desired location at the Ekofisk Tank. Structures to be used are presented in Table 3.4. The scenario for Alternative 1 is presented in Figure 3.19.

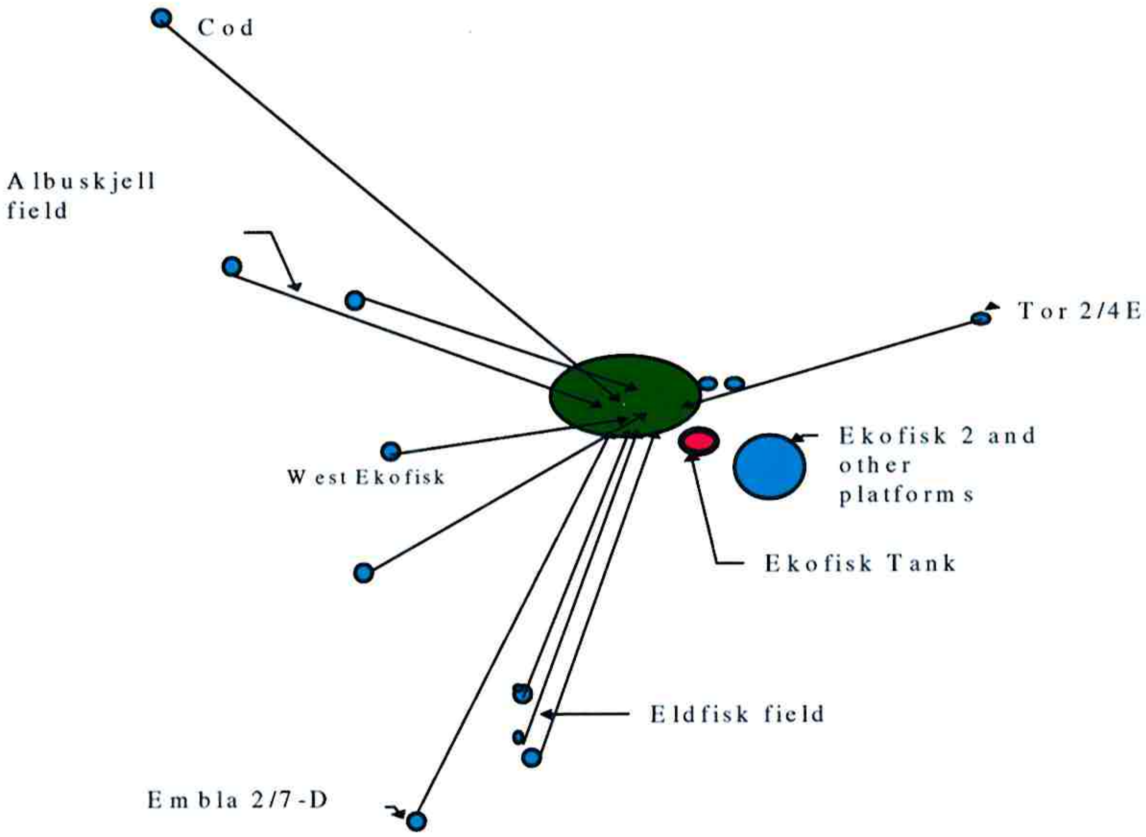

Figure 3.19*: Scenario for alternative 1. Reef creation at the Centre.*

3.6.3.2 Scenarios for Alternative 2: (Tank, Eldfisk)

Phase 1: A reef will be created north-west of the Ekofisk Tank containing structures that will be decommissioned in the period 1998 - 2005. Six jackets will be toppled in place, and 7 jackets will be placed on the north-west side of the tank.

Phase 2: After 2005 there are 11 platforms left at the Greater Ekofisk field, 10 will be placed to the west of Eldfisk 2/7-B. Eldfisk 2/7-B will be toppled in-place.

Structures to use are presented in Table 3.5. The scenario for Alternative 2 is presented in Figure 3.20a and 3.20b.

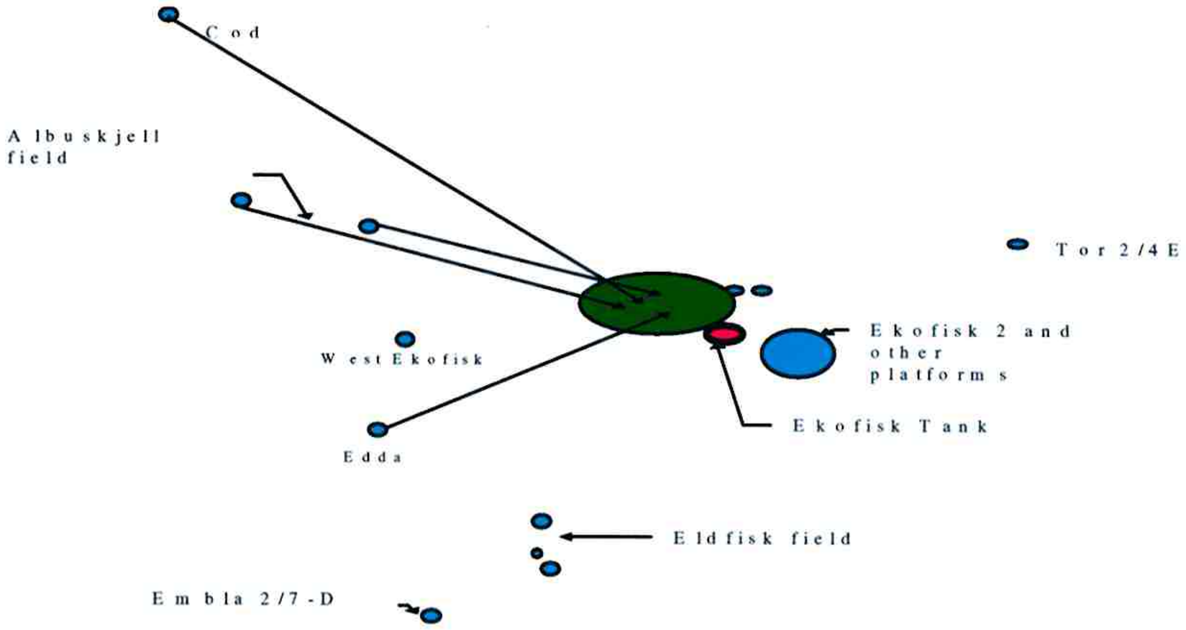

***Figure 3.20a**: Scenario for alternative 2, phase 1. Reef site north-west of the Tank*

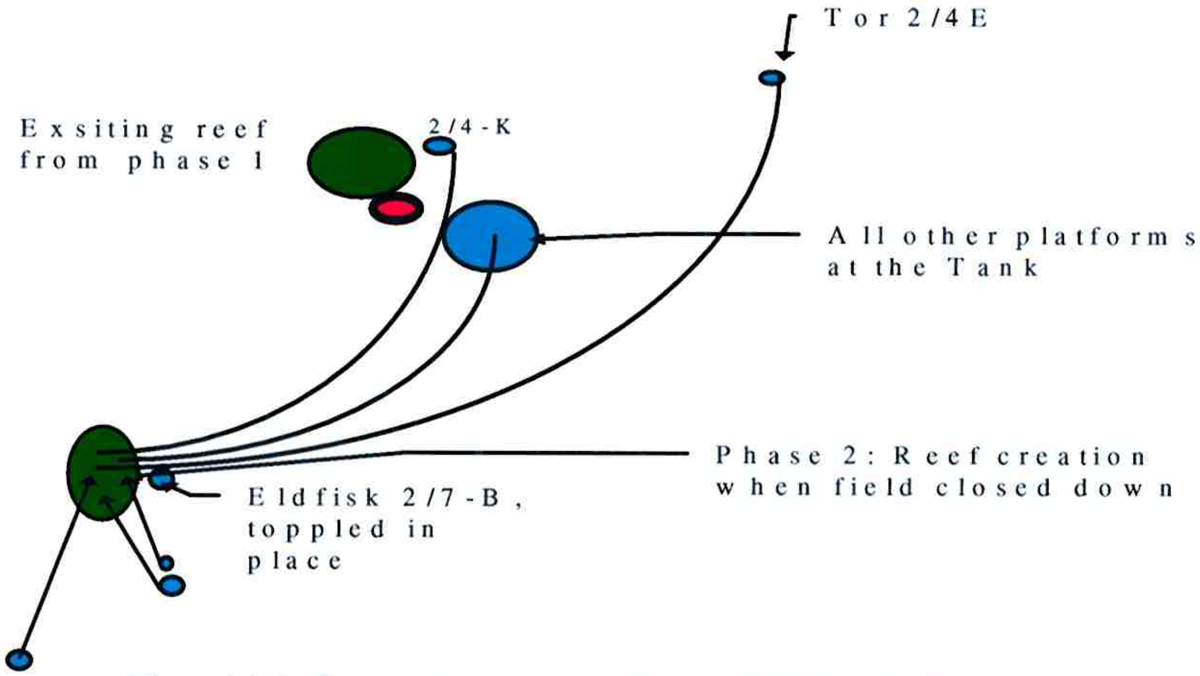

***Figure 3.20b**: Scenario for alternative 2, phase 2. Eldfisk 2/7-B as reef site.*

3.6.3.3 Scenarios for Alternative 3: (Centre, Tank)

Phase 1: A reef will be created at Ekofisk B/K containing structures that will be decommissioned in the period 1998 - 2005. Six jackets will be toppled in place, and 7 jackets will be placed at Ekofisk B/K.

Phase 2: After 2005 there are 11 platforms remaining, including Eldfisk 2/7-B. Five platforms will be transported to the Ekofisk Centre, and six platforms will be toppled in-place when the whole field is closed down.

Structures to use are presented in Table 3.6. The scenario for Alternative 3 is presented in Figure 3.21a and 3.21 b.

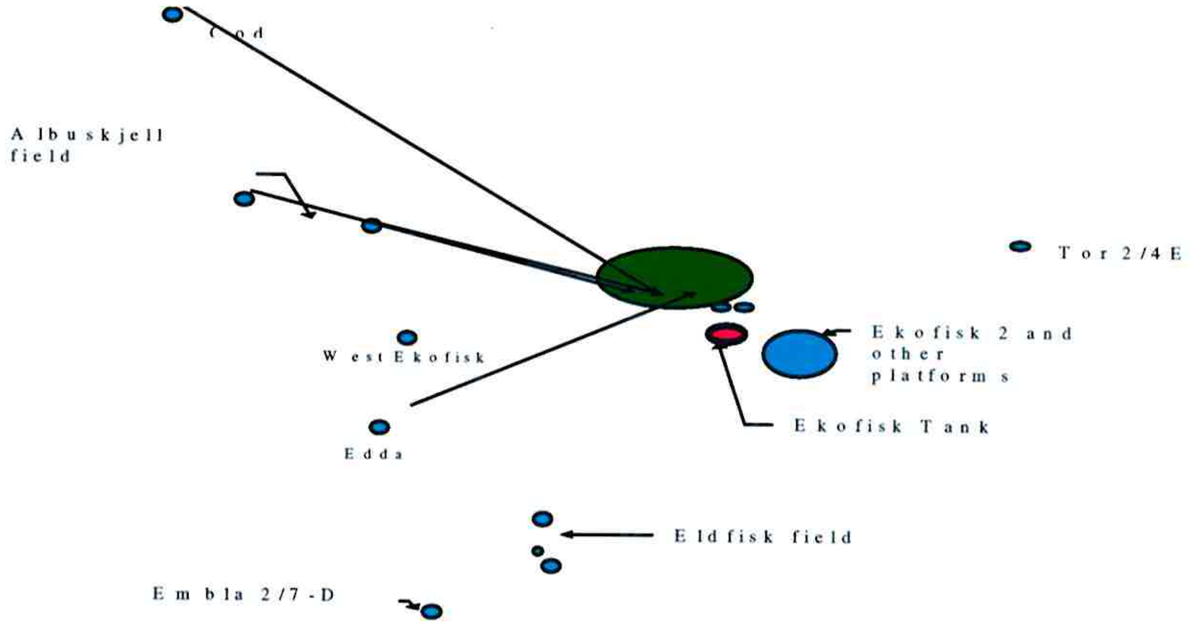

***Figure 3.21a**: Scenario for alternative 3, phase 1. Reef site at Ekofisk 2/4-B/K.*

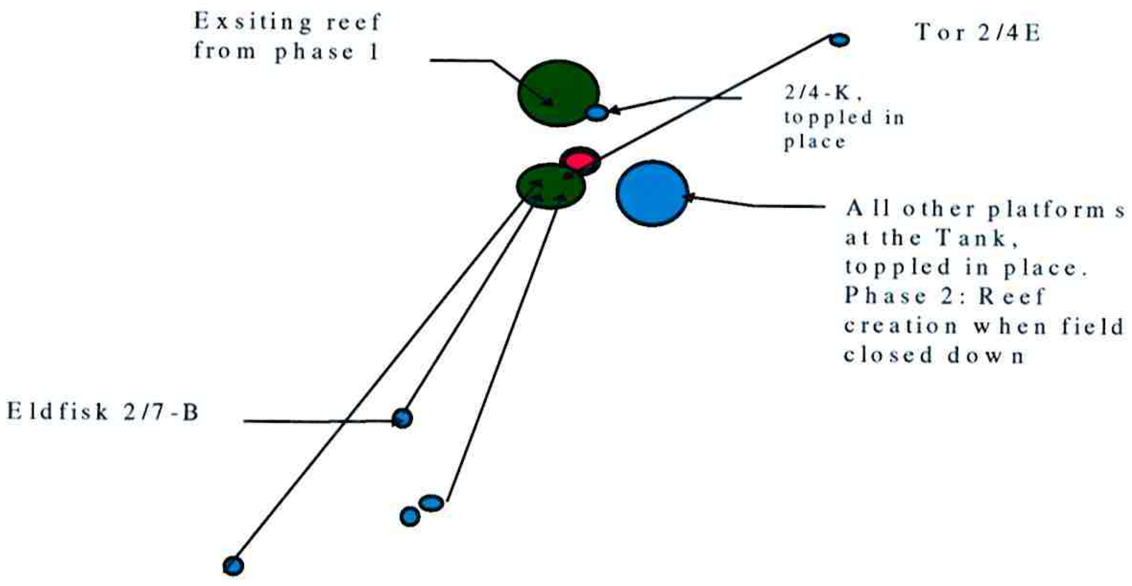

***Figure 3.21b**: Scenario for alternative 3, phase 2. Reef site at Ekofisk Centre, and existing reef at Ekofisk 2/4-B/K form phase 1.*

3.6.3.4 Scenarios for Alternative 4: (Albuskjell, Eldfisk)

Phase 1: Structures decommissioned in the period 1998 - 2005 will be placed at the Albuskjell 1/6-A reef site. Albuskjell 1/6-A can be toppled, and hence 12 platforms will be moved up to this site.

Alternative 4, Phase 2: After 2005 there are 11 platforms left at the Greater Ekofisk field, 10 will be placed to the west of Eldfisk 2/7-B. Eldfisk 2/7-B will be toppled.

Structures to use are presented in Table 3.7. The scenario for Alternative 4 is presented in Figure 3.22a and 3.22 b.

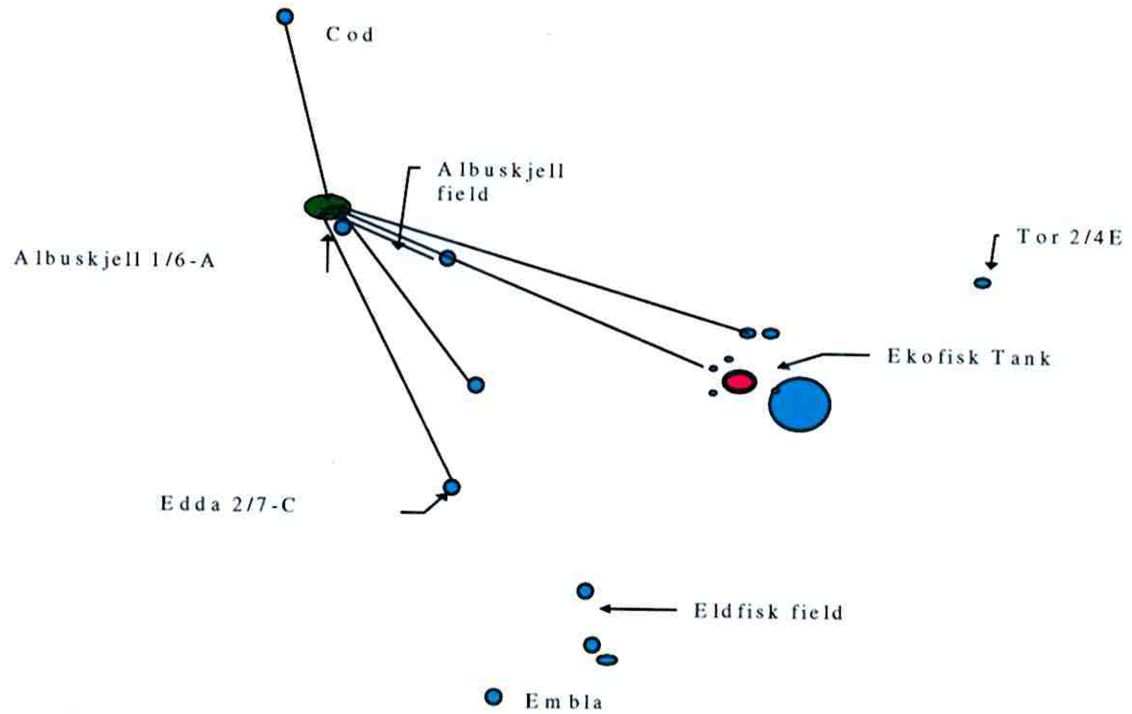

Figure 3.22a: *Scenario for alternative 4, phase 1, Albuskjell 1/6-A as reef site.*

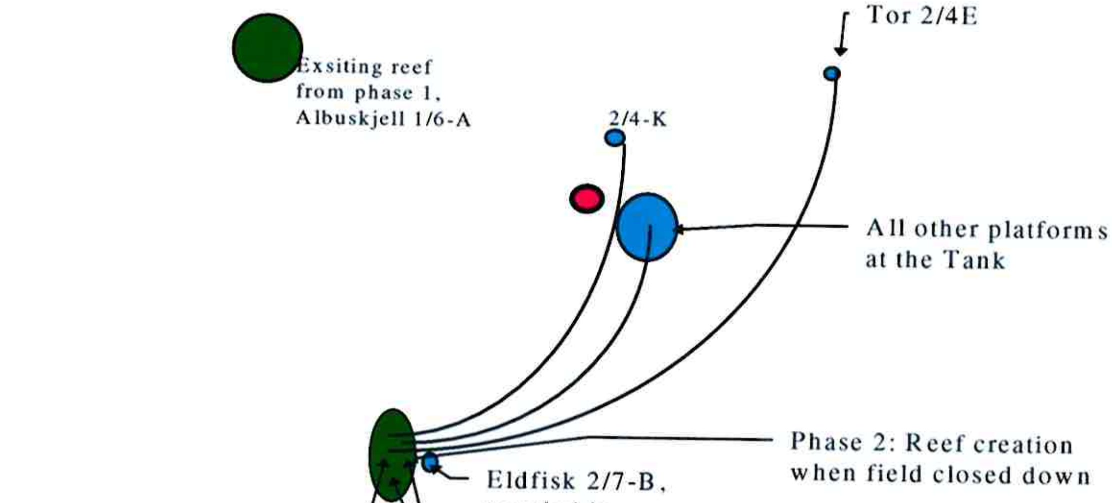

Figure 3.22b: *Scenario for alternative 4, phase 2. Eldfisk 2/7-B as reef site.*

3.6.3.5 Scenarios for Alternative 5: (Albuskjell, Tank)

Phase 1: Structures decommissioned in the period 1998 - 2005 will be placed at the Albuskjell 1/6-A reef site. Albuskjell 1/6-A can be toppled, and hence 12 platforms will be moved up to this site.

Phase 2: After 2005 there are 11 platforms remaining, including Eldfisk 2/7-B. Five platforms will be transported to the Ekofisk Tank, and six platforms will be toppled in place when the whole field is closed down.

Structures to use are presented in Table 3.8. The scenario for Alternative 5 is presented in Figure 3.23a and 3.23b.

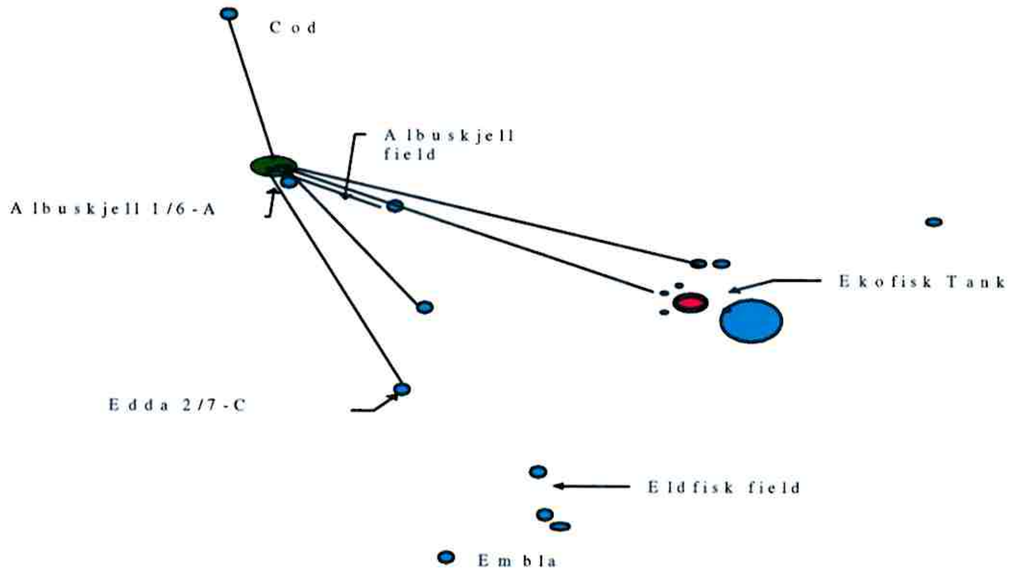

Figure 3.23a: *Scenario for alternative 5, phase 1, Albuskjell 1/6-A as reef site.*

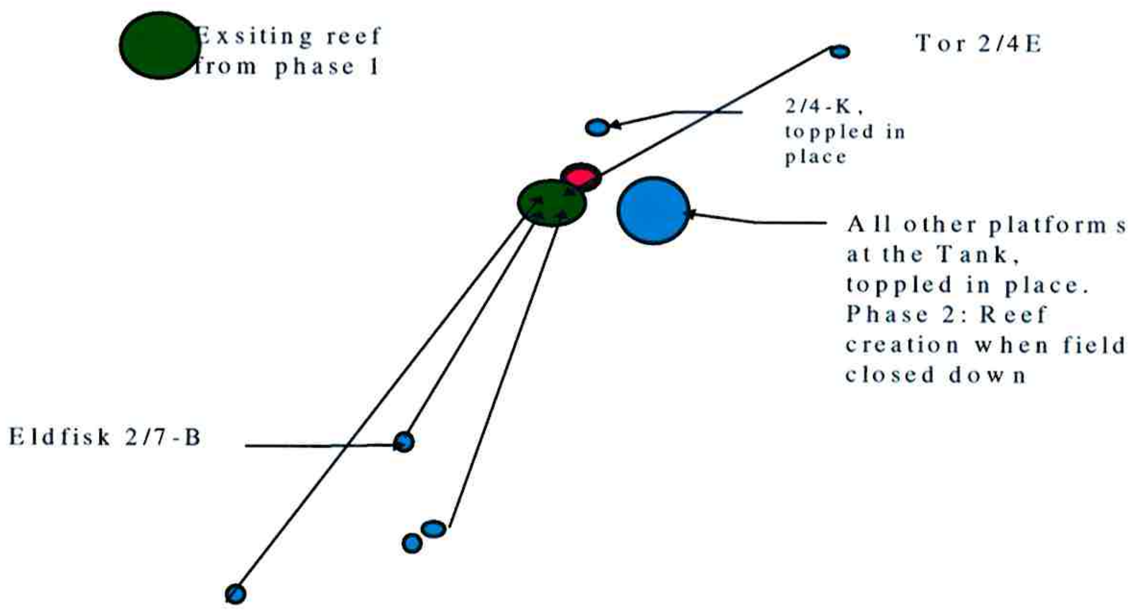

Figure 3.23b: *Scenario for alternative 5, phase 2. Ekofisk Tank as reef site.*

3.6.3.6 Scenarios for Alternative 6: (In situ toppling)

In situ toppling, i.e. all platforms at the Greater Ekofisk Field will be toppled in-place as they become decommissioned. Platforms around the Ekofisk Tank can be toppled in predetermined directions to optimise the reef configuration.

A discussion of this alternative is presented in section 3.3.4.3, *Single jacket reef sites*. Structures to use are the same as Alternative 1, which is presented in Table 3.4.

In Appendix 3.1 these scenarios are presented and Geographical Information System (GIS) maps. The GIS system was used to accurately position the platforms to be either toppled in-place or transported to a reef site.

3.7 Further Work

3.7.1 Introduction

The work required to follow on from aspects described in Report 3 relates mainly to plans for the optimal design of reefs to maximise benefits and minimise costs, based on the Alternative chosen by PPCoN. The following aspects are described:

1. The work to be conducted.
2. How and when this is to be done.
3. What type of results may be expected.
4. How these results will assist the overall evaluation process.

3.7.2 Proposal for work to be conducted

The following work will need to be conducted:

1. Technical assessment of the reef implementation
2. Reef implementation plan for the alternative(s)
3. Time frame for the reef implementation
4. General assessment for the reef implementation

3.7.3 Task 1: Technical assessment of the reef implementation

3.7.3.1 How this is to be done

- Capacity evaluation of existing vessels (SSCV and others) and whether they can achieve the proposed reef configuration.
- Identification of platform weight/size limitations (e.g. with 2/4K, Ekofisk II).
- How can the operations be implemented using existing equipment?
- Evaluation of any technical limitations of the Alternatives proposed in the Ekoreef report.
- Evaluation of methods (pull barge or SSCV, etc.) to use, for the toppling in place and/or removal/transportation of any reef component.

3.7.3.2 When this is to be done

This will serve as a basis for the identification of technical limitations. It must be conducted prior the reef implementation plan.

3.7.3.3 Type of results expected

Identification of the technical limitations associated with the reef implementation, and what methods should be used. The task will also list suitable vessels.

3.7.3.4 How these results assist the overall evaluation process

This will give an indication as to whether the Alternatives chosen are technically feasible to implement.

3.7.4 Task 2: Reef implementation plan for the alternative(s)

3.7.4.1 How this is to be done

- After one or more of the Alternatives (1-11) is decided upon, then a defined implementation plan for each reef component will need to be created.
- The location of each platform and its accompanying reef components will need to be defined in order to optimise the reef configuration.
- Each reef component should have a defined orientation, based on the prevailing currents and other reef components.
- If the platform is to be toppled, what toppling direction should be used (juxta position of the components)?
- If transported, what distance should it have to the next component when placed at the reef location (defined to some extent in the current study).
- Decision as to whether the platform is to be subjected to total or partial toppling.
- Potential for the incorporation of old pipelines, i.e. platforms toppled on top of old pipelines.

3.7.4.2 When this is to be done

This plan can be done after PPCoN has decided what alternative(s) they want to implement. Firstly, the whole concept of the Ekoreef must be approved. PPCoN could also decide on a combination of the alternatives presented.

3.7.4.3 What type of results may be expected

The result will be in the form of a reef implementation plan, with drawings. Each reef component will have a defined location in a reef. The reasons for why and where each reef component is to be placed will also be presented.

3.7.4.4 How these results assist the overall evaluation process

These results will clarify where each structure is placed, and hence the drawings can be presented to authorities, NGO's, fishermen, and the public. This will serve as a basis for the time-frame for the reef implementation process.

3.7.5 Task 3: Time-frame for reef implementation

3.7.5.1 How this is to be done

- Time-frame (schedule/timing) for the reef implementation, including the order in which the platforms will be toppled or removed and transported.
- Use of vessels, workforce, existing operating platforms, economy and environmental aspects will be discussed.
- The objective is also to find operational windows for the reef implementation related to local conditions, including spawning time, weather, marine mammal migration, and other conflicting activities in general.

3.7.5.2 When this is to be done

The time-frame for the implementation of the reef configuration can be proposed once the reef implementation plan has been drafted. Aspects of this time-frame must be incorporated into the reef implementation plan, so as to minimise costs and maximise benefits.

3.7.5.3 What type of results may be expected

The result of this will be a step-by-step plan for the incorporation of each component into the reef configuration. Suggestions for any operational windows for the reef implementation.

3.7.5.4 How these results assist the overall evaluation process

This relates to PPCoN's resources, such as workforce availability, economy, time schedule related to other activities, other companies involved (Statoil, Amoco). Basically this helps the overall evaluation process to find out if PPCoN has the available resources before and under the reef implementation.

3.7.6 Task 4: General and environmental assessment of the reef implementation

3.7.6.1 How this is to be done

- An overall assessment of the reef implementation activities, related to the interaction with operating platforms, existing vessel traffic, traffic lanes, and/or fishing activities.
- Risk assessment in relation to the existing production and impacts on the environment, i.e. short term-impacts that can be avoided. This issue is related to the process of implementing the whole reef configuration.
- The quantification of material present on the seabed as artificial reef components will need to be conducted.
- This will lead to an extended discussion related to long-term effects and leaching rate of these different substances, e.g. steel, anodes, cadmium, etc.

3.7.6.2 When this is to be done

This would be the last task to be conducted. The reef plan and time frame for the implementation will have been proposed, and limitations presented The process and long terms effects can then be assessed.

3.7.6.3 What type of results may be expected

Special issues of concern during the implementation process, and leaching rates of the material present on the seabed will need to be addressed. A list of what issues will be presented, and how problems can be solved should be discussed.

3.7.6.4 How these results assist the overall evaluation process

The overall evaluation process will benefit from this assessment in terms of identifying the problems that can occur during reef implementation, and hence create a flexible decision-making process. The quantification of material on the seabed, will help to evaluate if leaching rates will influence the acceptance of the Ekoreef from a legislative point of view.

3.8 Conclusion and Recommendations

From the available information, the following conclusions can be drawn.

3.8.1 Artificial reefs locations

1. In terms of the general oceanographic impacts on the reef, a jacket or several jackets on the sea-bed will be influenced by the flows in the region. Some scouring may occur, but this is not expected to have any negative effect on the stability on the reef itself, and may even increase the available habitat niches marginally.

2. Reef(s) created at the Greater Ekofisk field may potentially be used to benefit the fishing industry. Future research is required to quantify the extent and nature of this benefit, if it indeed exists.

3. Three drill cuttings disposal options for sea-bed restoration around platform reef locations are suggested. Seen from an environmental perspective, locations with contaminants from drill cuttings should be avoided. This recommendation is based on the precautionary principle only, because there is little information available to indicate that the efficiency of a reef, or its organisms, would be significantly harmed by such contamination.

4. The three main criteria used to estimate the suitability of a site for an artificial reef were: location of pipelines; sediment contaminant concentration and distribution; location of available platforms.

5. The Ekofisk Tank is suggested as an artificial reef site, because: it is assumed to be abandoned; it is a convenient location, i.e. several platforms may be toppled in-place at this site; the tank is relatively immovable and could act as a reef core or locus. The contamination concentration and distribution around the Tank is not as low as would be desired, but there are indications the levels will decline in the future because of cleaner production.

6. The Albuskjell 1/6-A and Eldfisk 2/7-B are also suggested as artificial reef sites because: there are few pipelines in the vicinity; the sediment contamination concentration and distribution is low and limited; and their location are convenient in relation to other platforms to become available in the area.

7. *In situ* toppling is suggested as an potential alternative because: the cost of the reef implementation is low; the reef configuration is easy; the Greater Ekofisk field may still serve as a refuge through restricted fishing zone.

3.8.2 Reef structures

8. There are 24 platforms that will be available for use as artificial reef components. They are all considered stable structures when placed on the sea-bed, with an expected lifetime of over 150 years.

9. Cutting of the jacket legs at or below the sea-bed is one of the main technical challenges associated with the relocation of the jackets. The toppling of the whole jacket in-place by the use of explosive cutting is the best and cheapest option.

10. Reef components can be relocated using a Controlled Variable Buoyancy System (CVBS), a Semi Submersible Crane Vessel (SSCV), or by using a pull barge. Further research and development is required for all three options.

11. The main criteria influencing the suitability and expected efficiency of structures comprising a reef complex are: volume and structural complexity of the structure; the potential for toppling in-place, as opposed to transportation; economic lifetime of the jacket.

12. A detailed evaluation of all structures to use at the three potential reef sites at Ekofisk Tank, Albuskjell 1/6-A and Eldfisk 2/7-B indicates that some structures are more suitable than others, depending on which Alternative is decided upon.

3.8.3 Design of artificial reefs

13. The design of a reef is dependant on its proposed purpose. The reef may be configured: in a straight line for assisting fishing; assembled in blocks or circular patterns for fish stock protection or habitat protection; by inserting structures within each other for greater reef complexity.

14. Four main criteria need to be considered during the design of a platform reef: orientation, i.e. compass direction of main axis of the reef; juxta-position of jackets within a reef complex; number of jackets in a complex; distance between jackets in and between complexes.

3.8.4 Scenarios at Ekoreef

15. Optimal reef scenarios for assisting fishing and habitat protection are based on the criteria for the design of the platform reefs. An optimal reef scenario does consider criteria such as: orientation, i.e. compass direction of reef; juxta-position of jackets within reef; number of jackets at the reef; and distance between jackets in the reef.

16. Seen purely from the aim of enhanced fishing, reefs laid out in straight lines are considered most beneficial.

17. Seen purely from the aim of habitat / environmental protection, reefs laid out in a series of circular patterns are considered most beneficial.

18. From a purely financial aspect Alternative 6, i.e. *in-situ* toppling, appears likely to be most beneficial. Second choice after this would then be Alternative 1, i.e. creation of a reef at the Ekofisk Tank using structures as they become available until all of the platforms are decommissioned.

19. From a purely environmental (contamination) aspect, the avoidance of the Ekofisk Tank area appears most desired, i.e. Alternative 4; Albuskjell 1/6-A as reef site with all structures decommissioned in 1998-2005, and another reef site at Eldfisk 2/7-B with all structures decommissioned after 2005.

20. The main alternatives suggested in this study are:

1. Alternative 1 (Centre): A single complex reef will be created around the Ekofisk Tank using structures as they become available, until all of the platforms are decommissioned after 2028.
2. Alternative 2 (Tank, Eldfisk): A reef will be created north-west of the Ekofisk Tank using platforms decommissioned before 2005. A second reef will be created at Eldfisk 2/7-B using platforms decommissioned after 2005.
3. Alternative 3 (Centre, Tank): A reef will be created at Ekofisk B/K containing structures that will be decommissioned before 2005. The reef will be expanded at the Ekofisk Tank and a second reef complex created with platforms decommissioned after 2005.
4. Alternative 4 (Albuskjell, Eldfisk): A reef will be created at Albuskjell 1/6-A using platforms decommissioned before 2005. A second reef will be created at Eldfisk 2/7-B using platforms decommissioned after 2005.
5. Alternative 5 (Albuskjell, Tank): A reef will be created at Albuskjell 1/6-A using platforms decommissioned before 2005. The reef will be created at the Ekofisk Tank and a second reef complex created with platforms decommissioned after 2005.
6. Alternative 6 (In situ toppling): All platforms at the Greater Ekofisk Field will be toppled in-place as they become decommissioned.

3.9 References

Aabel, J.P., Cripps, S.J., Jensen, A.C., and Picken, G. (1997). Creating artificial reefs from decommissioned platforms in the North Sea: review of knowledge and proposed programme of research. E & P Forum Report. 129pp.

Anderson, T.W., Martini, E.E. and Roberts, D.A. (1989). The relationship between habitat structure, body size and distribution of fishes at a temperate artificial reef. Bulletin of Marine Science, 44(1): 681-697.

Anon (1993). Konsekvensutredning. Ekofisk plan for utbygging og drift (Impact statement. Ekofisk plan for development and operation). Phillips Petroleum Company Norway as, Stavanger, Norway.

Bearman, P. W. and Zdravkovich, M. N. (1978). Flow around a circular cylinder near a plane boundary. J. Fluid Mech., 89: 33-47.

Bohnsack, J.A, Johnson, D.L. and Ambrose, R.F. (1991). Ecology of artificial reef habitats and fishes. *In*: Seaman W & Sprague LM (eds). Artificial habitats for marine and freshwater fisheries. Academic Press Inc. pp. 77-83.

Bohnsack, J.A., and Sutherland, D.L. (1985). Artificial reef research: A review with recommendations for future priorities. Bulletin of Marine Science, 37(1): 11-39.

Breusers, H.N.C., Nicollet, G, and Shen, H. W. (1977). Local scour around cylindrical piers. J. Hydr. Rev., 1 (3): 211-252.

Brørs, B. (in subm.). Flow and scour at pipelines. J. Hydr. Eng.

Corresist AS. 1995. Odin offshore artificial reef management plan. Estimation of remaining lifetime. pp 1-23. Appendix In: Kjeilen, G., Aabel, J.P., Høyvangli, V., Baine, M., Picken, G., and Heaps, L. (1995). ODIN - an artificial reef study. Rogaland Research Report No. RF 138/94.

Cripps, S.J., Kjeilen, G. and Aabel, J.P. (1995) Ekofisk artificial reef. Rogaland Research Report, RF 95/205.

Cripps, S.J., Aabel, J.P. and Kjeilen, G. (1996). Using artificial reefs as fisherman's management tools. Proceedings of the Safety and Management in Abandonment Conference, Aberdeen, UK, Jan. 31-Feb. 1, 1996. Euroforum: London. 18 pp.

Cripps, S.J.; *et al.* (1998). Disposal of oil-based cuttings. RF-Rogaland Research. Report, RF-1998/097. pp 140.

Dames & Moore (1996). Final Draft Report, Recommended framework procedure for rendering an offshore installation clean on behalf of Oljeindustriens Landsforening (OLF). Project 33150-001.

Davies, J.M. & Kingston, P.F. 1992. Sources of environmental disturbance associated with offshore oil and gas developments. In: *North Sea Oil and the Environment: Developing Oil and Gas Resources, Environmental Impacts and Responses.* (Ed. W.J. Cairns). University Press: Cambridge, UK. Pp 417-440.

Davies, J.M., Bedborough, D.R., Blackman, R.A.A., Addy, J.M., Appelbee, J.F., Grogan, W.C., Parker, J.G. and Whitehead, A. (1988). The environmental effect of oil-based mud drilling in the North Sea. Proceedings of the 1988 International Conference on Drilling Wastes, Calgary, Alberta, Canada 5-8th April 1988, Elsevier, pp.59-89.

Driessen, P.K. (1985). Oil platforms as reefs. Oil an fish can mix. pp.1417-1438. *In*: Coastal Zone Conference. American Society of Civil Engineers, 2.

Daan, N, Bromley, P.J., Hislop, J.R.G. and Nielsen, N.A. (1990). Ecology of North Sea Fish. Netherlands Journal of Sea Research, 26: 343-386.

Daan, R. & Mulder, M. 1995. Long-term effect of OBM cutting discharges in the sedimentation area of the Dutch continental shelf. NIOZ report 1995-11. NIOZ: Texel, Holland. 25 pp.

FAO (1990). Shellfish culture associated with artificial reefs. FAO report. ISBN 92-5-002981-0.

Grove, R.S., Sonu, C.J. and. Nakamura, M. (1989). Recent Japanese trends in fishing reef design and planning. Bulletin of Marine Science, 44(2): 984-996.

Jørgensen, E. & Mannvik, H.P. (1994). Environmental monitoring survey of the Ekofisk Centre and Eldfisk 2/7 B fields, May 1994. Phillips Petroleum Company Norway as, Stavanger, Norway, 78 pp.

Kjeilen, G., Aabel, J.P., Høyvangli, V., Baine, M., Picken, G., and Heaps, L. (1995). ODIN - an artificial reef study. Rogaland Research Report No. RF 138/94.

Mao, Y. (1986). The Interaction Between a Pipeline and an Erodible Bed. Institute of Hydrodynamics and Hydraulic Engineering, Technical University of Denmark, Lyngby, 169 pp.

Niedoroda, A.W. and Dalton, C. (1982). A review of fluid mechanics of ocean scour. Ocean Engng., 9(2), 159-170.

North Sea Task Force, (1993). North Sea Quality Status Report 1993. Oslo and Paris Commission (OSPARCOM): London.

Olbjørn, E.H. (1974). Utbygging av Ekofisk. *In*: Særkursseminar i marin teknologi, NTH, Bygningsingeniøravdelingen, Trondheim, Norway. Paris Commission (PARCOM), 1989. (In Norwegian).

Picken, G. (1995). An assessment of the environmental impacts of decommissioning options for oil and gas installations in the UK North Sea. AURIS Report MR270.

Schlichting, H. (1979). Boundary-Layer Theory. 7th Edition, McGraw Hill, 817 pp.

SLP, 1994. Joint Industry Project: Seabed Stability of Abandonment Remains, Preliminary Investigations. SLP Engineering, London. Report RE 253 001.

Solberg, T. (1992). A numerical study of laminar and turbulent separated flows over a circular cylider plane wall. Dr. Eng. Thesis, NTH, Division of Applied Mechanics, Trondheim. Norway. 188 pp.

Stanley, D.R, and Wilson, C.A. (1991). Factors affecting the abundance of selected fishes near oil and gas platforms in the Northern Gulf of Mexico. Fish. Bull: 89 (1): 149-159.

Stephan, C.D., Dansby, B.G., Osburn, H.R., Matlock, G.C., Riechers, R.K. and Rayborn R.. (1990). Texas artificial reef plan. Fisheries Management plan series No. 3. Texas Parks and Wildlife Department, Coastal Fisheries Branch.

Utnes, T. and Brørs, B. (1993). Numerical modelling of 3-D circulation in restricted waters. Appl. Math. Modelling, 17, 522-535.

3.10 Appendix

3.1 Visualisation of the proposed reef creation scenarios

For each scenario, 2 aims, and therefore designs are envisaged:

- (f) = fishing enhancement;
- (p) = habitat / environmental protection.

A total of 11 alternatives are proposed and visualised using GIS (Geographical Information System) technology. In all the scenario figures the new facilities Ekofisk 2/4-X and 2/4-J is included.

The key to the colour code used on the Figures is presented in Figure 3.26 below. The contamination concentration and distribution for Total Hydrocarbon (THC) concentration are from Report 2, Appendix 2.1. The colour code for size of platforms is also presented in Figure 3.24.

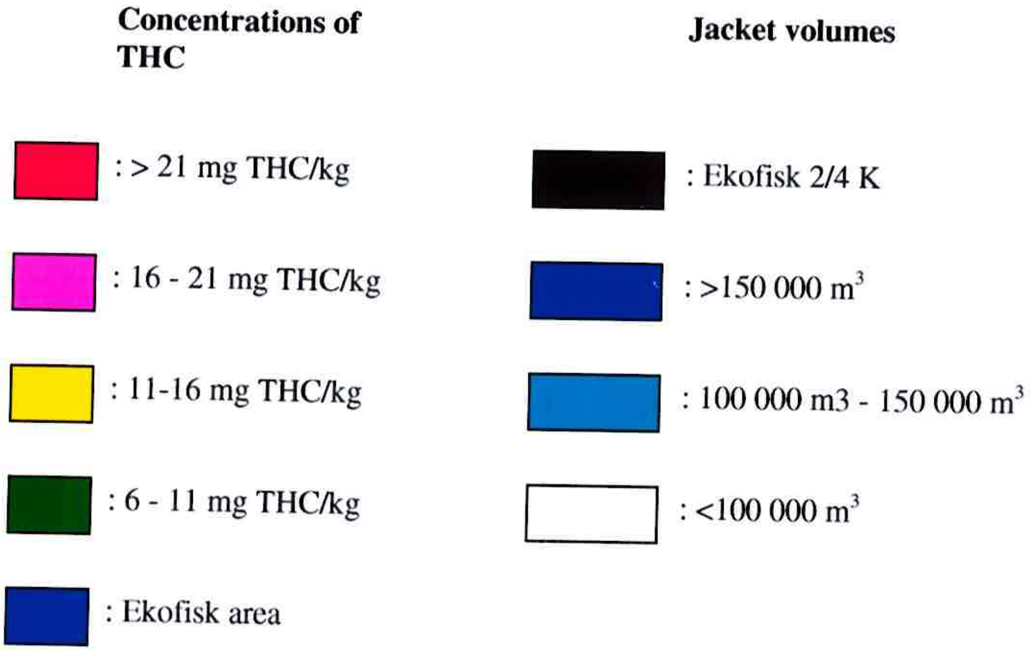

Figure 3.24: *Colour code for the THC concentrations and platform sizes shown in the GIS charts.*

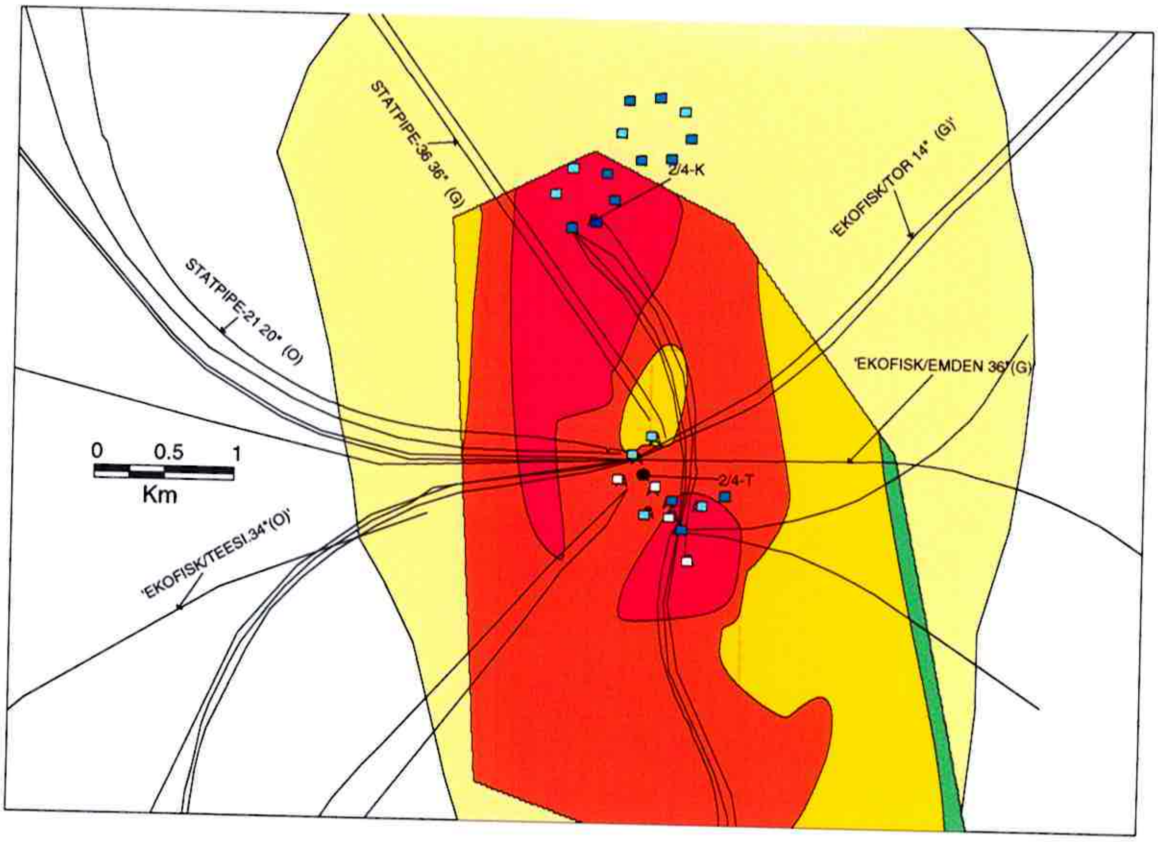

Figure 3.25: *Reef Alternative 1(Centre), for habitat protection.*

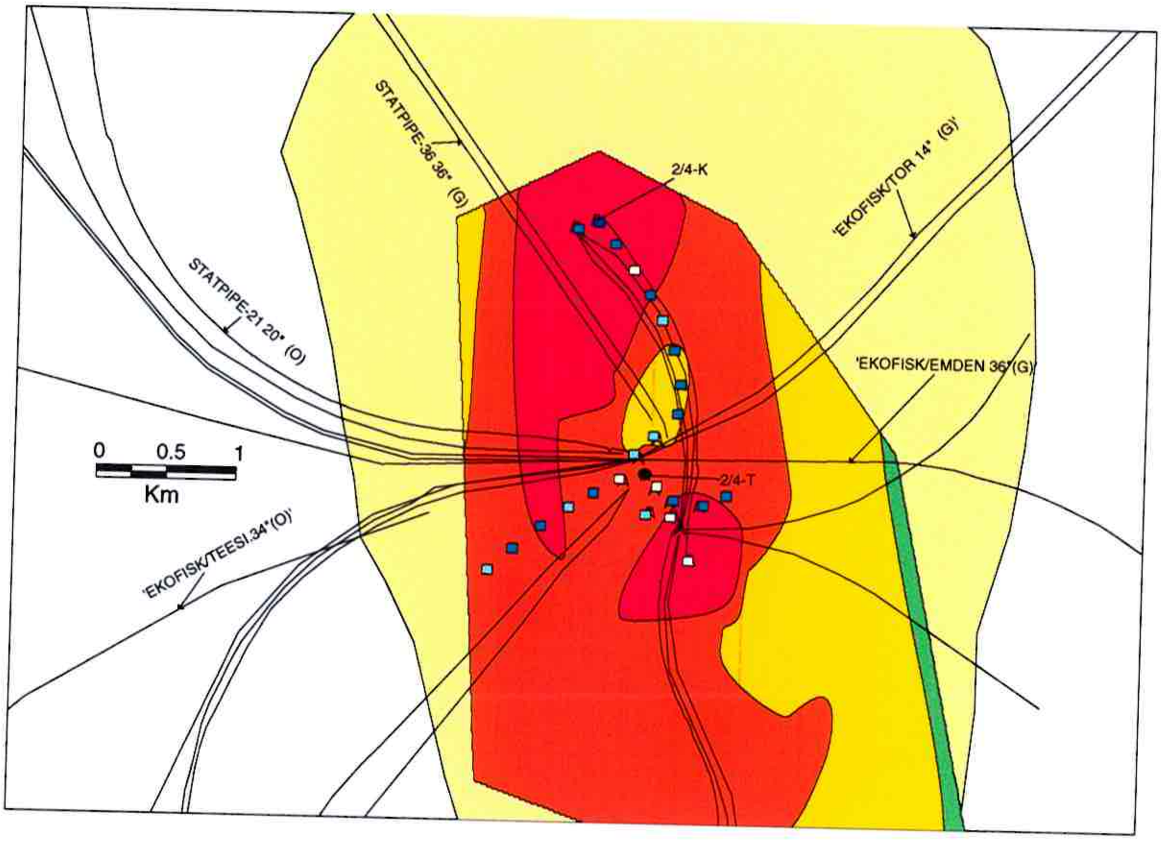

Figure 3.26: *Reef Alternative 1(Centre), for fishing enhancement.*

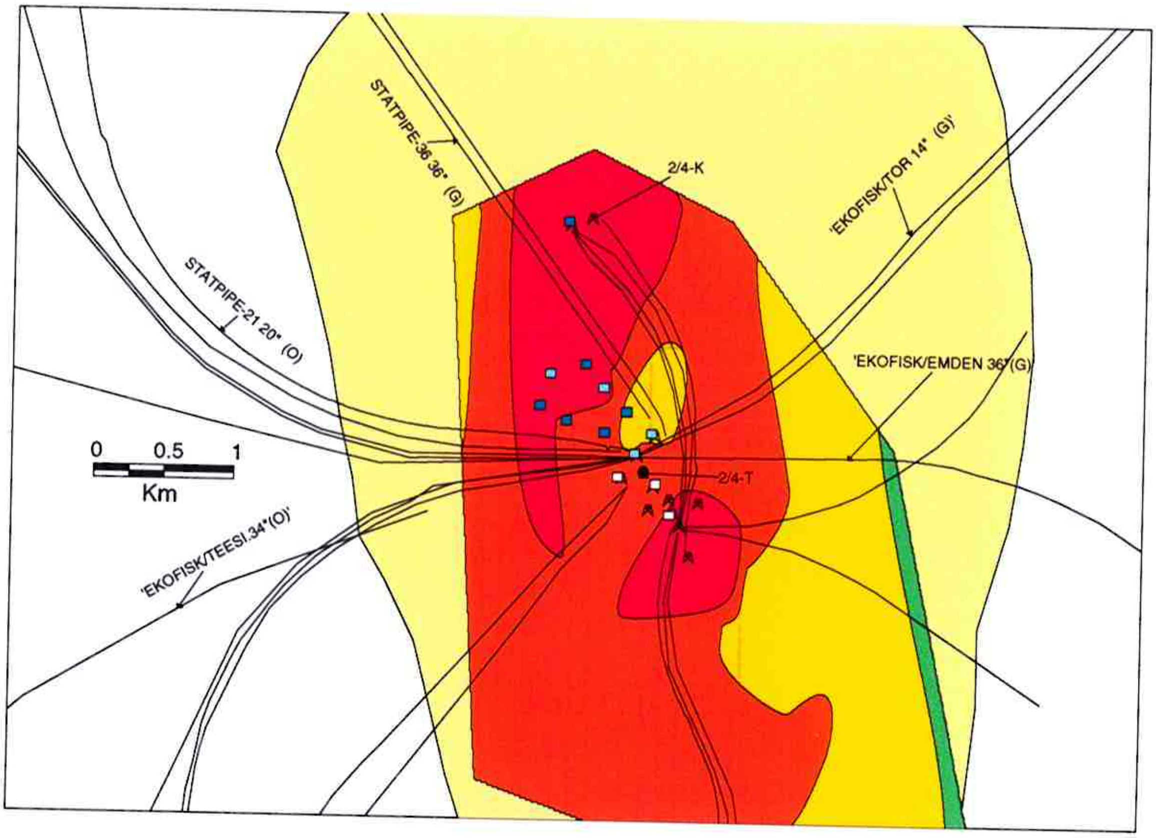

Figure 3.27: Reef Alternative 2(Tank), phase 1, for habitat protection

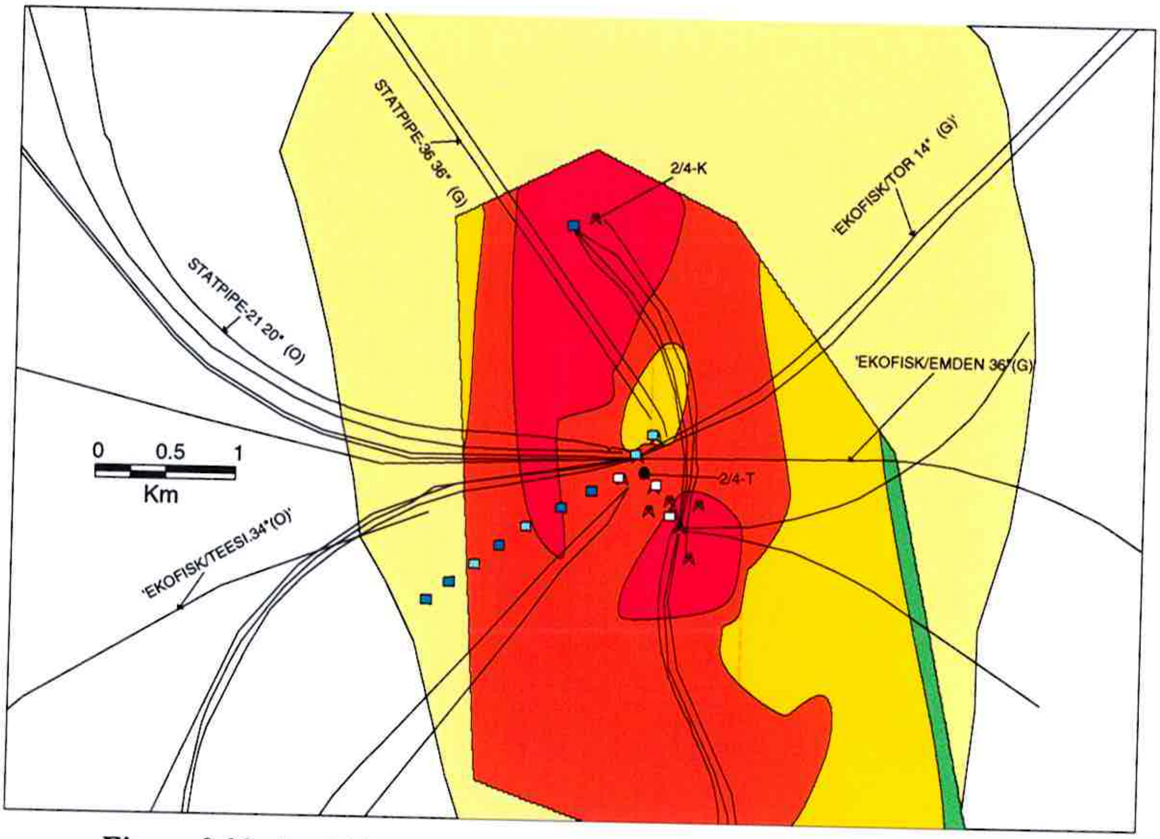

Figure 3.28: Reef Alternative 2(Tank), phase 1, for fishing enhancement.

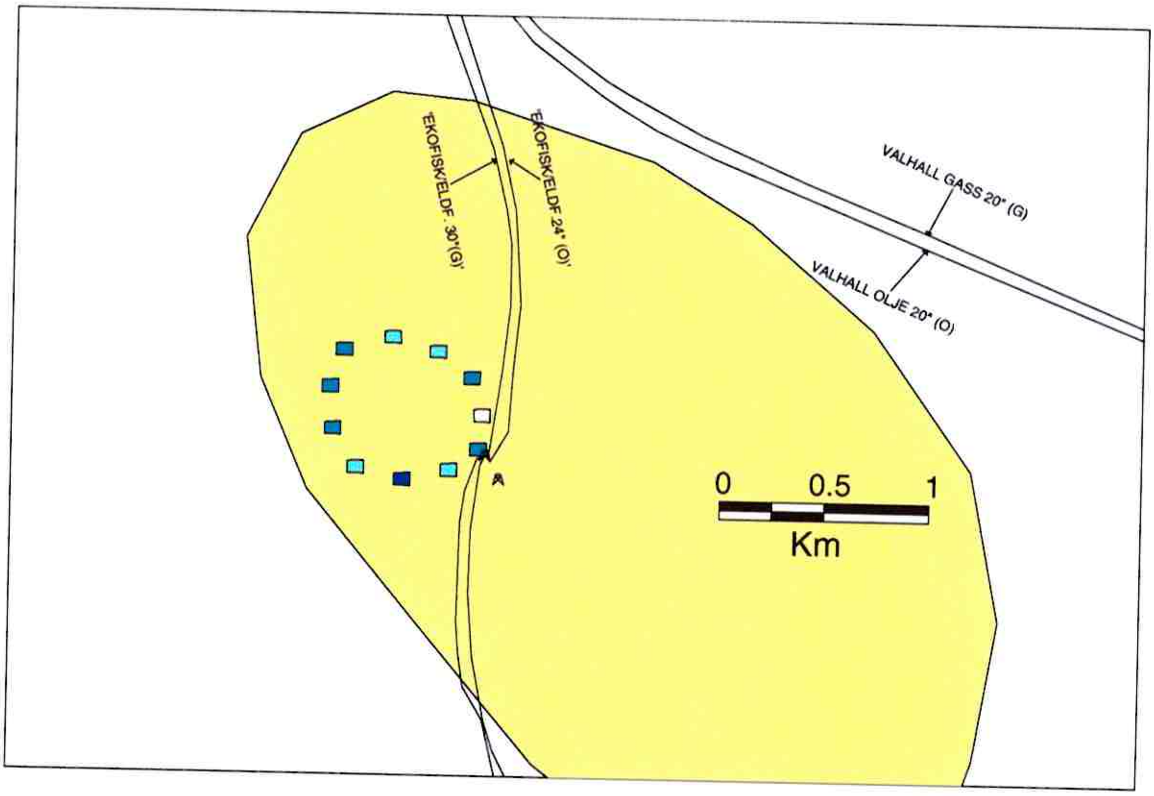

***Figure 3.29**: Reef Alternative 2(Eldfisk), phase 2, for habitat protection*

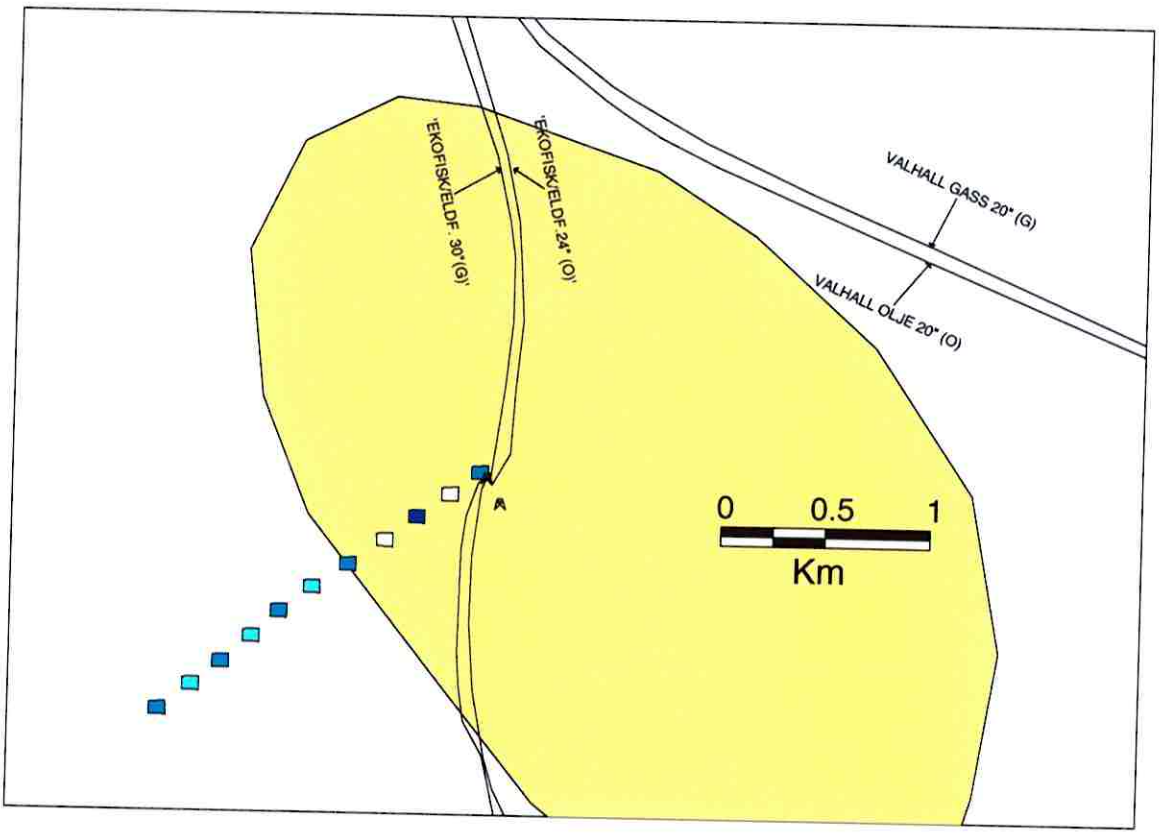

***Figure 3.30**: Reef Alternative 2(Eldfisk), phase 2, for fishing enhancement.*

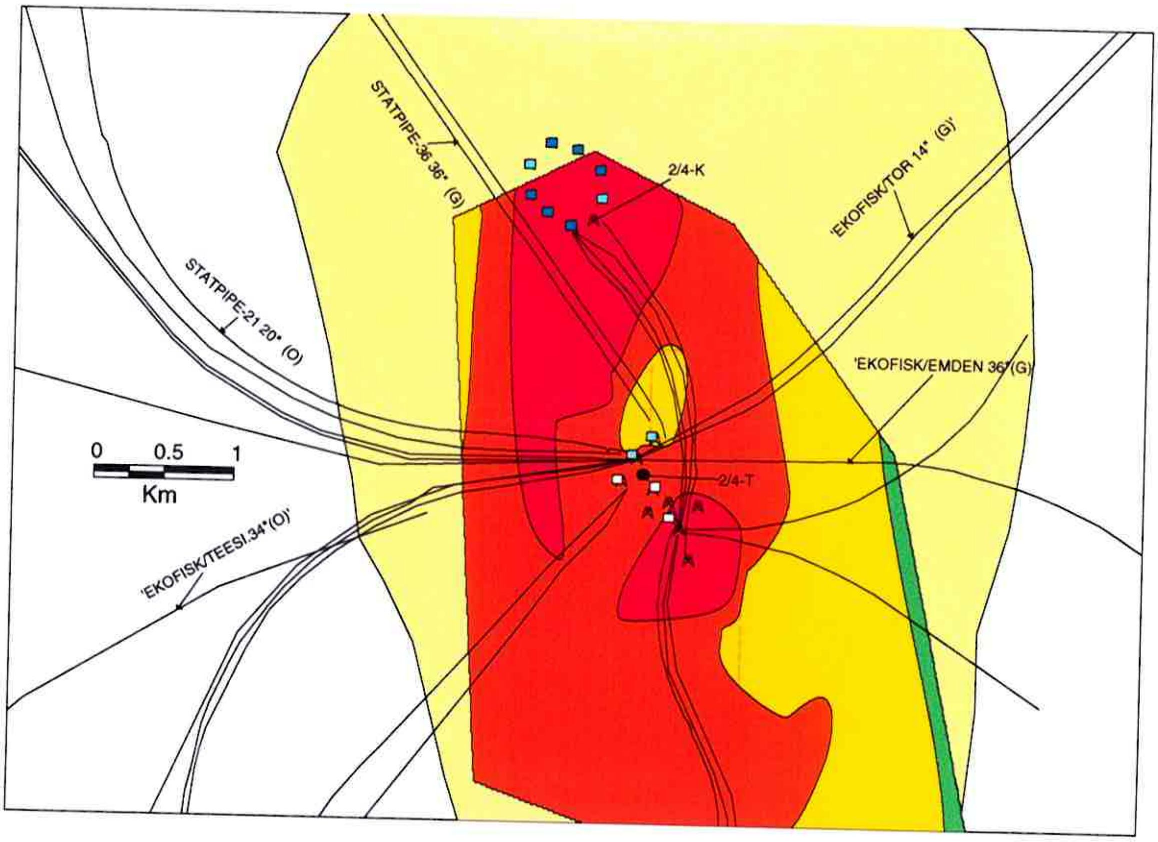

Figure 3.31: Reef Alternative 3(Centre), phase 1, for habitat protection

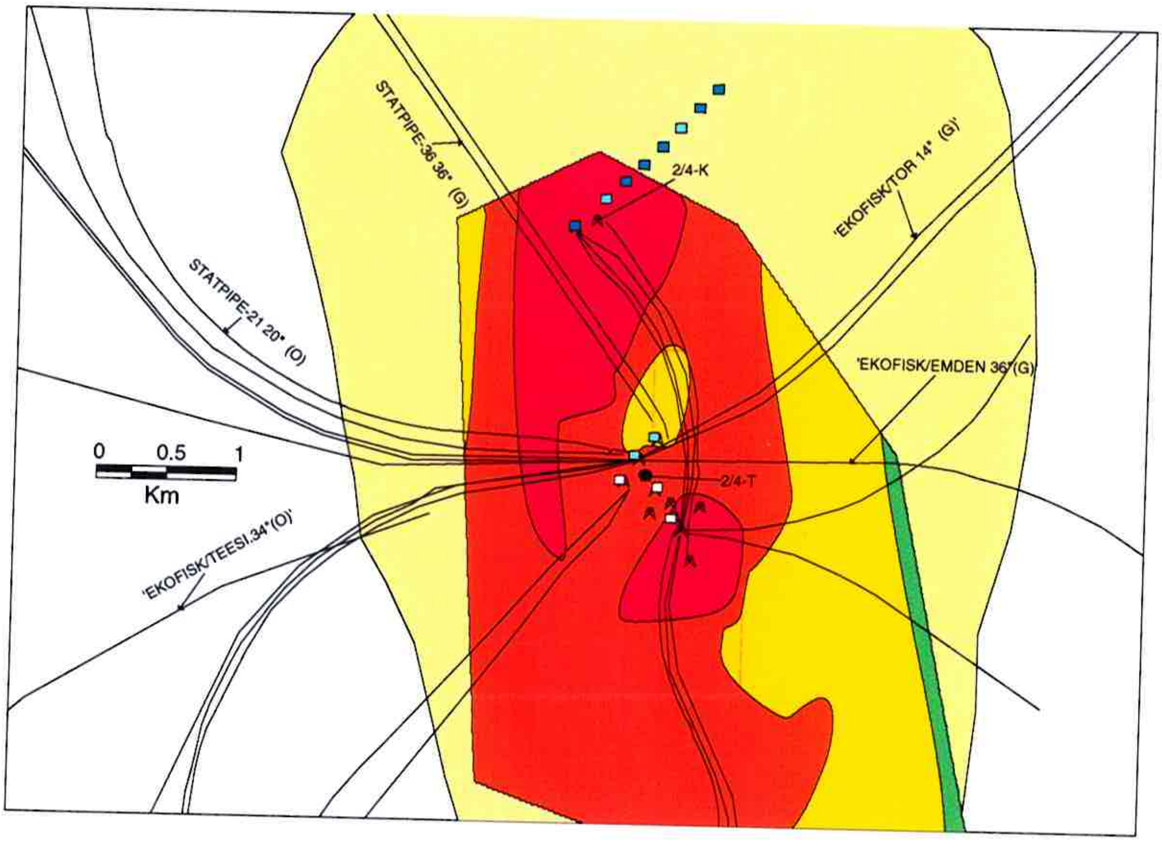

Figure 3.32: Reef Alternative 3(Centre), phase 1, for fishing enhancement.

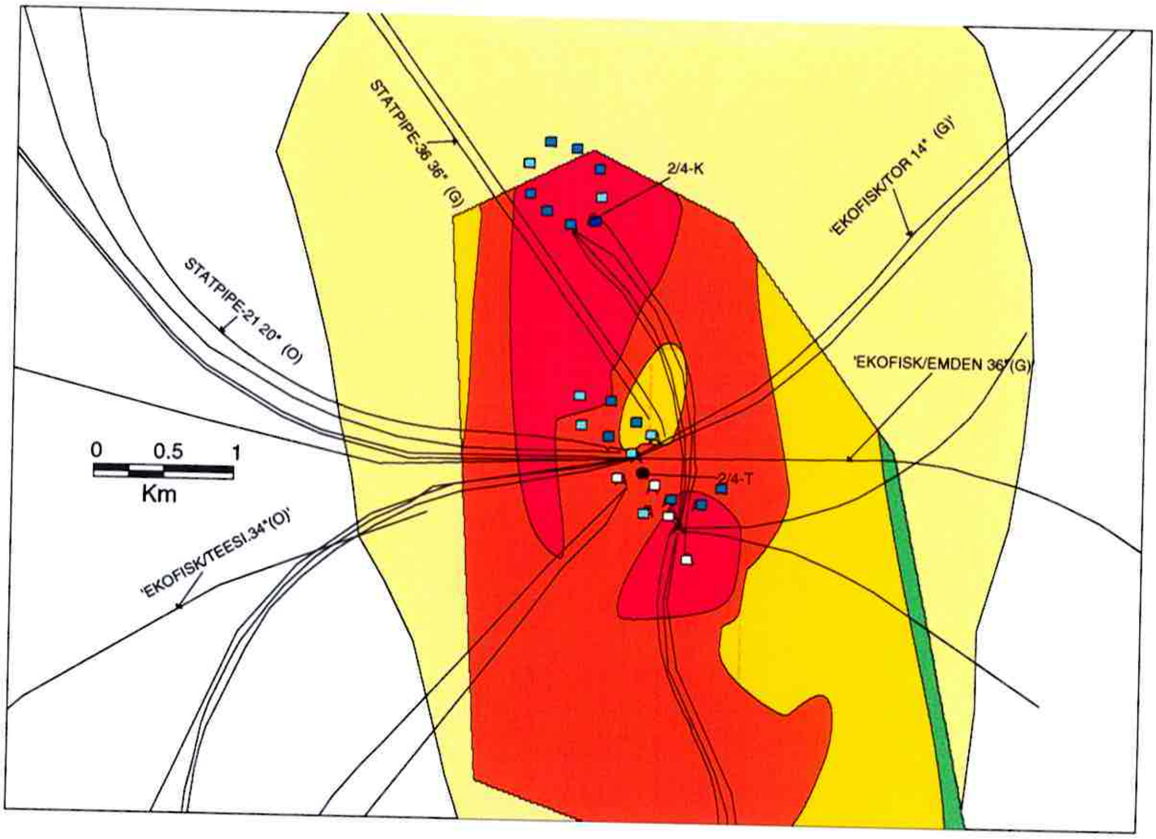

Figure 3.33: Reef Alternative 3(Tank), phase 2, for habitat protection

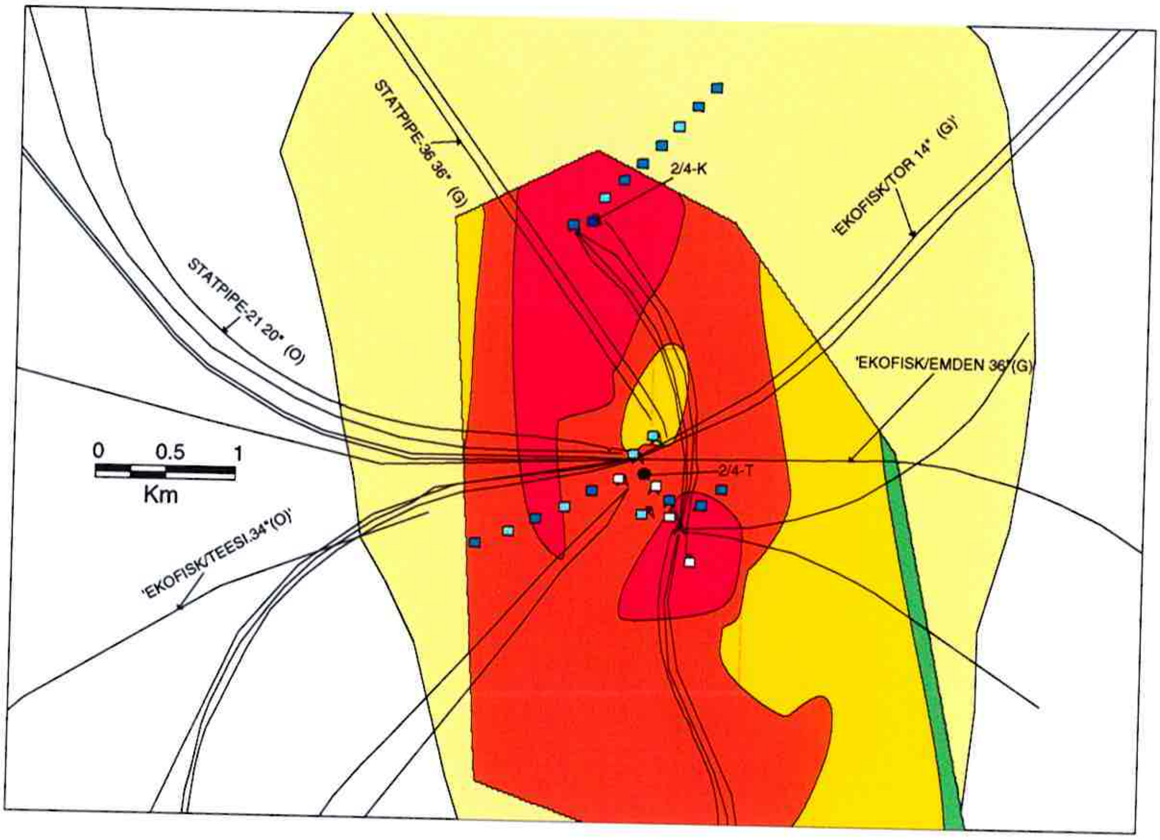

Figure 3.34: Reef Alternative 3(Tank), phase 2, for fishing enhancement.

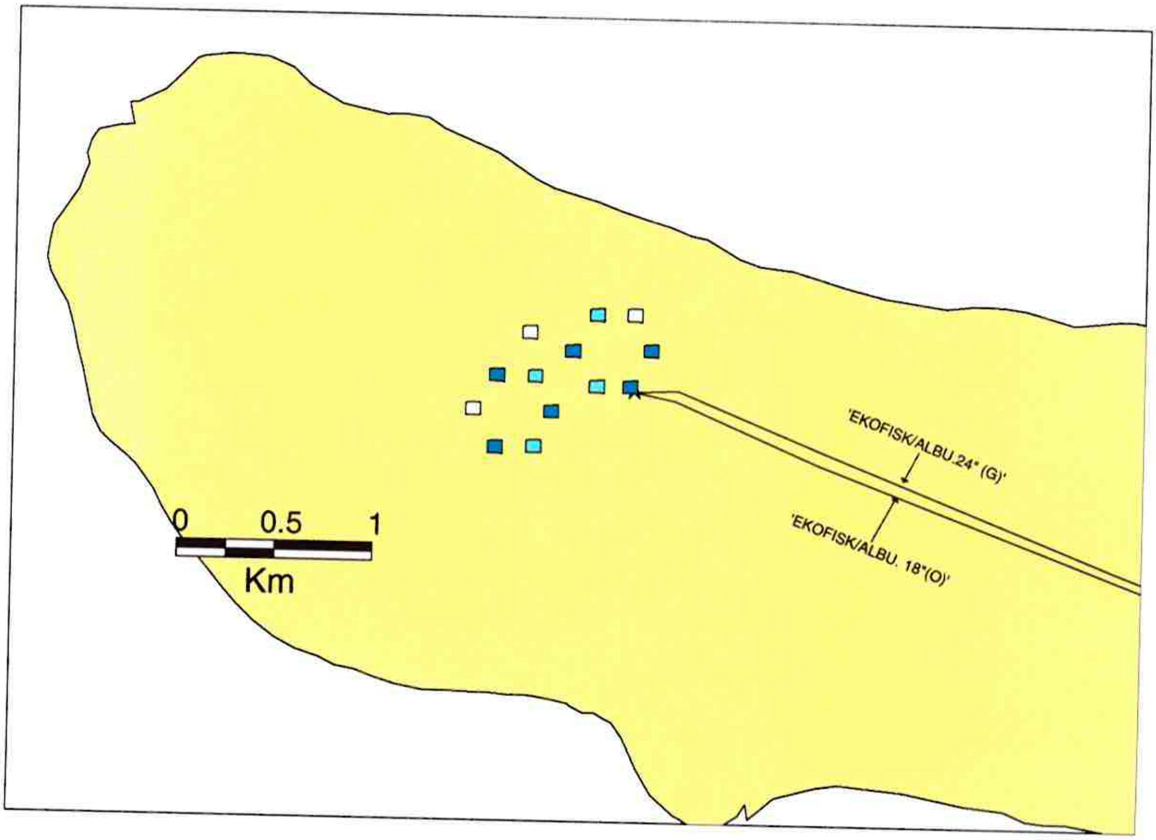

Figure 3.35: *Reef Alternative 4(Albuskjell), phase 1, for habitat protection.*

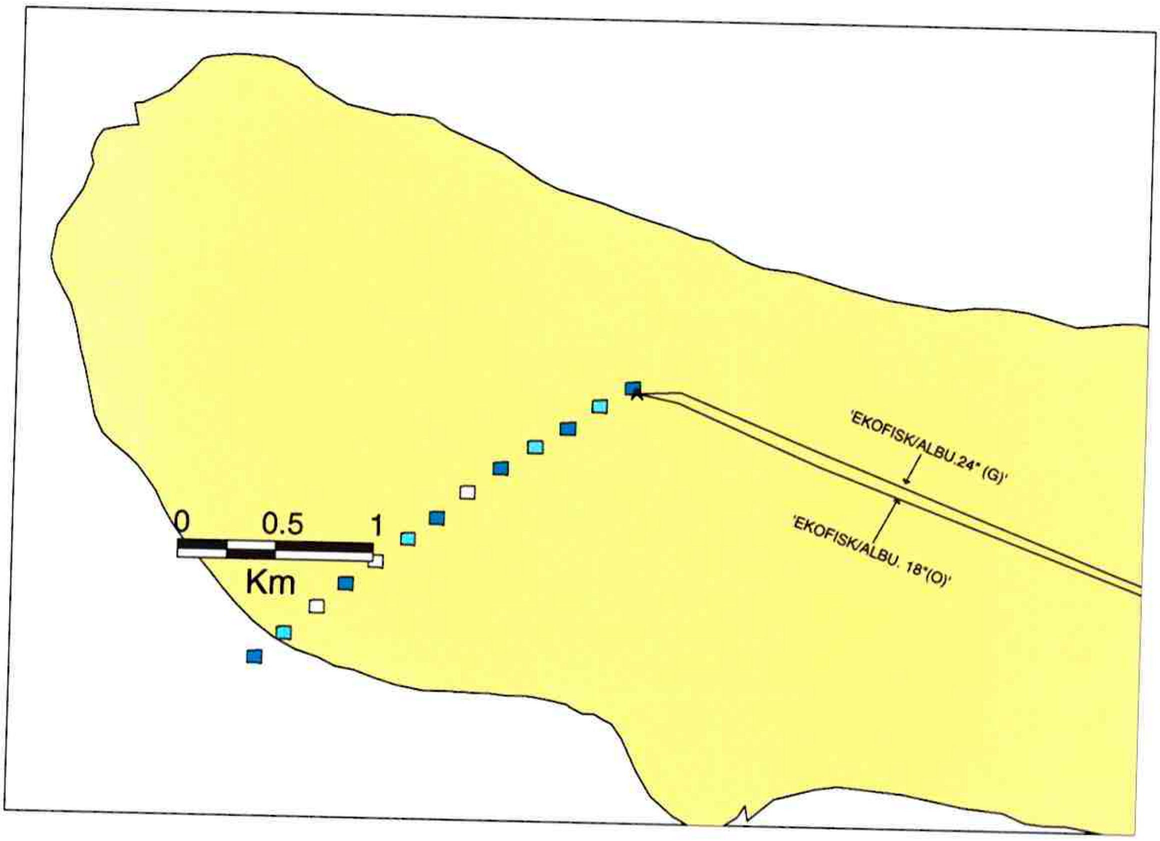

Figure 3.36: *Reef Alternative 4(Albuskjell), phase 1, for fishing enhancement.*

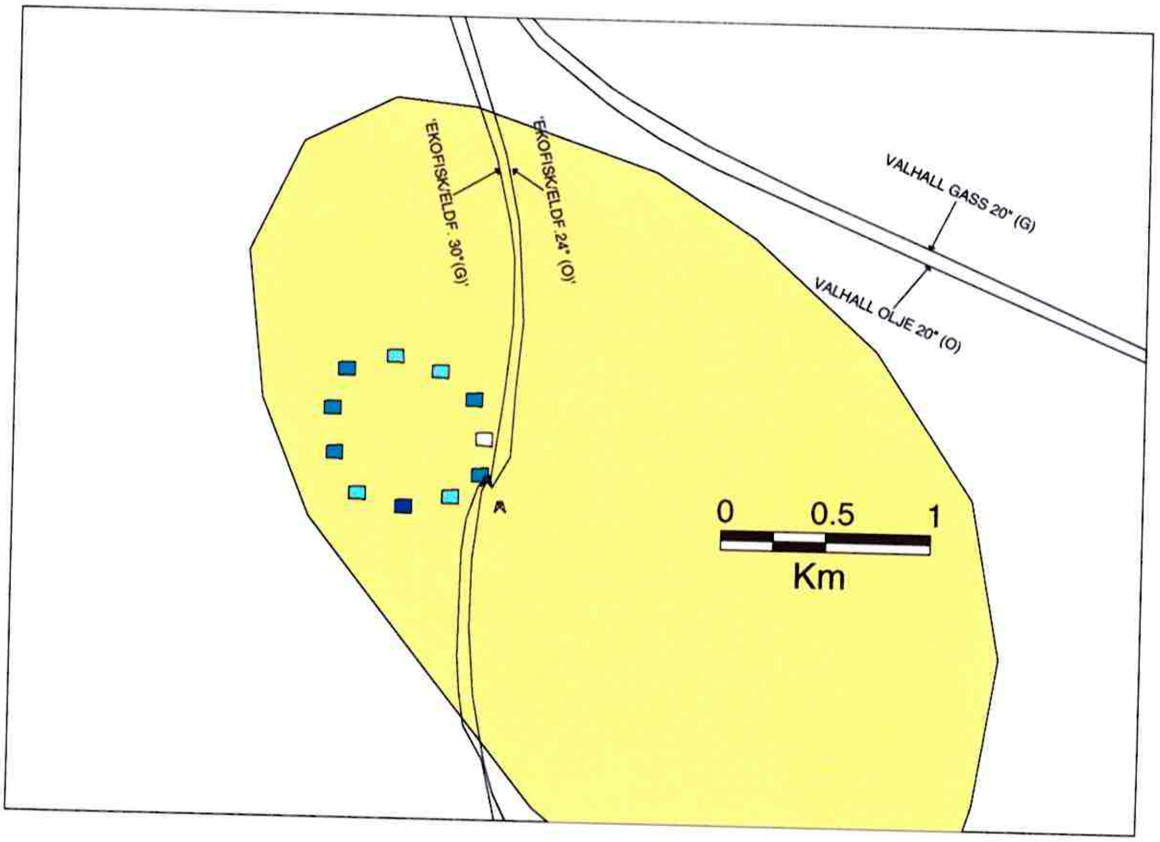

Figure 3.37: *Reef Alternative 4(Eldfisk), phase 2, for habitat protection*

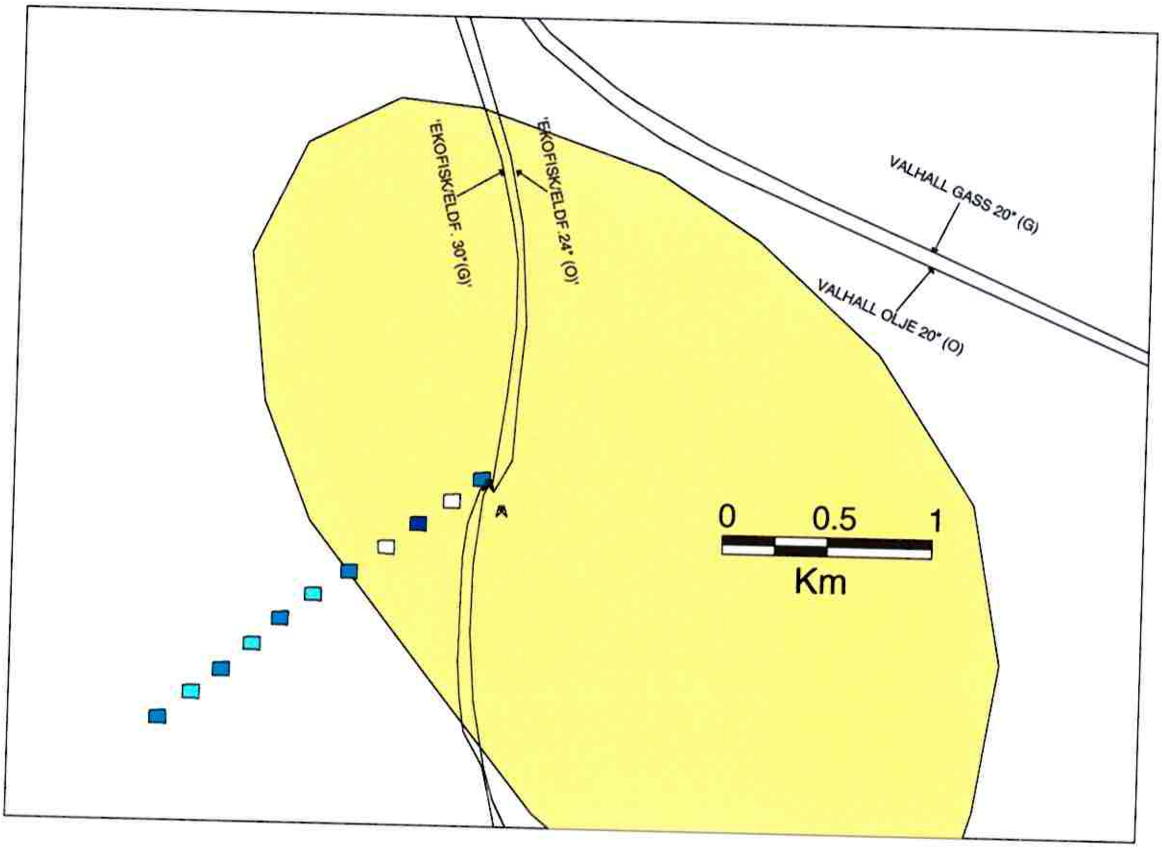

Figure 3.38: *Reef Alternative 4 (Eldfisk), phase 2, for fishing enhancement.*

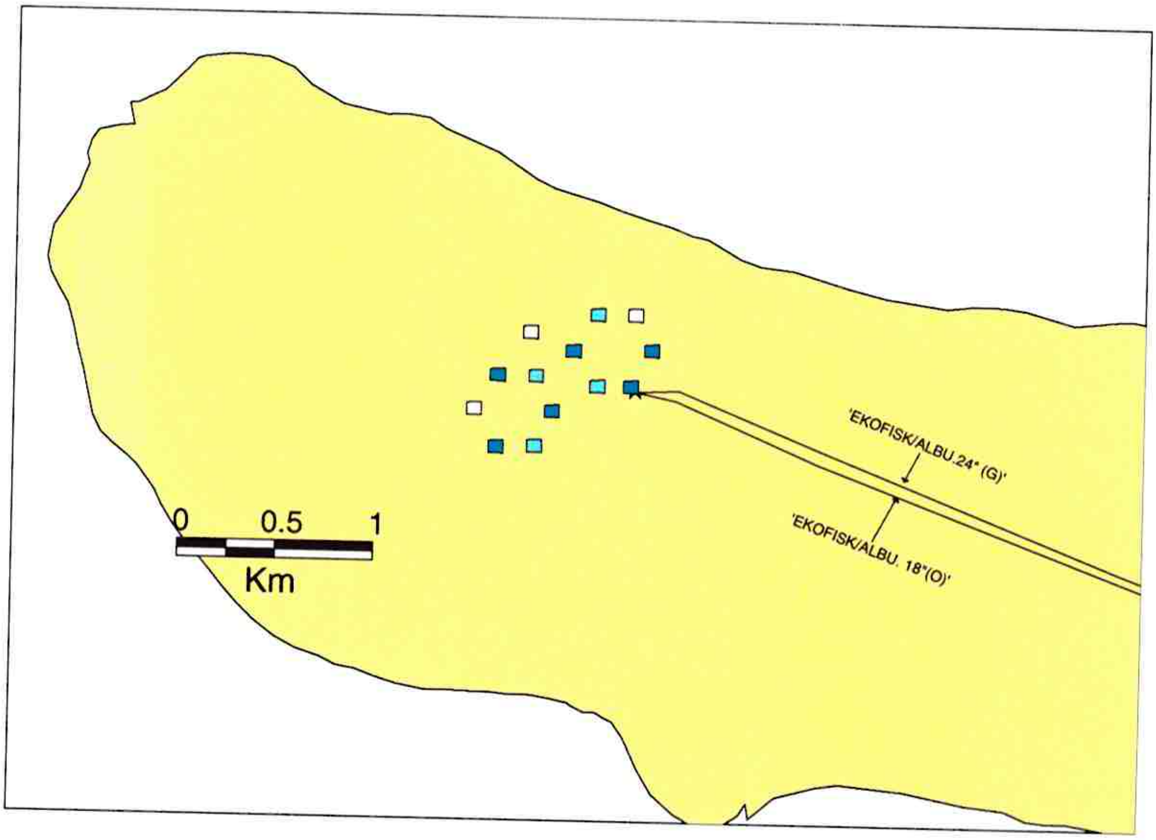

Figure 3.39: *Reef Alternative 5(Albuskjell), phase 1, for habitat protection.*

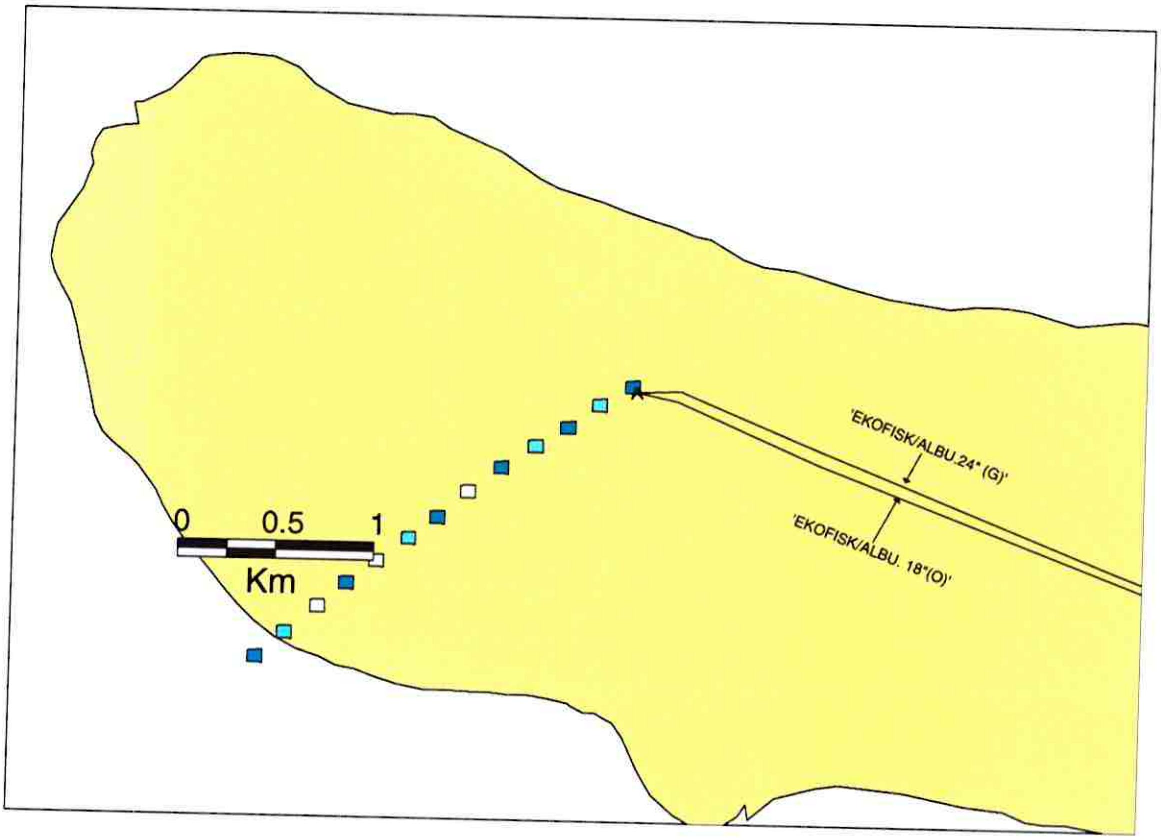

Figure 3.40: *Reef Alternative 5(Albuskjell), phase 1, for fishing enhancement.*

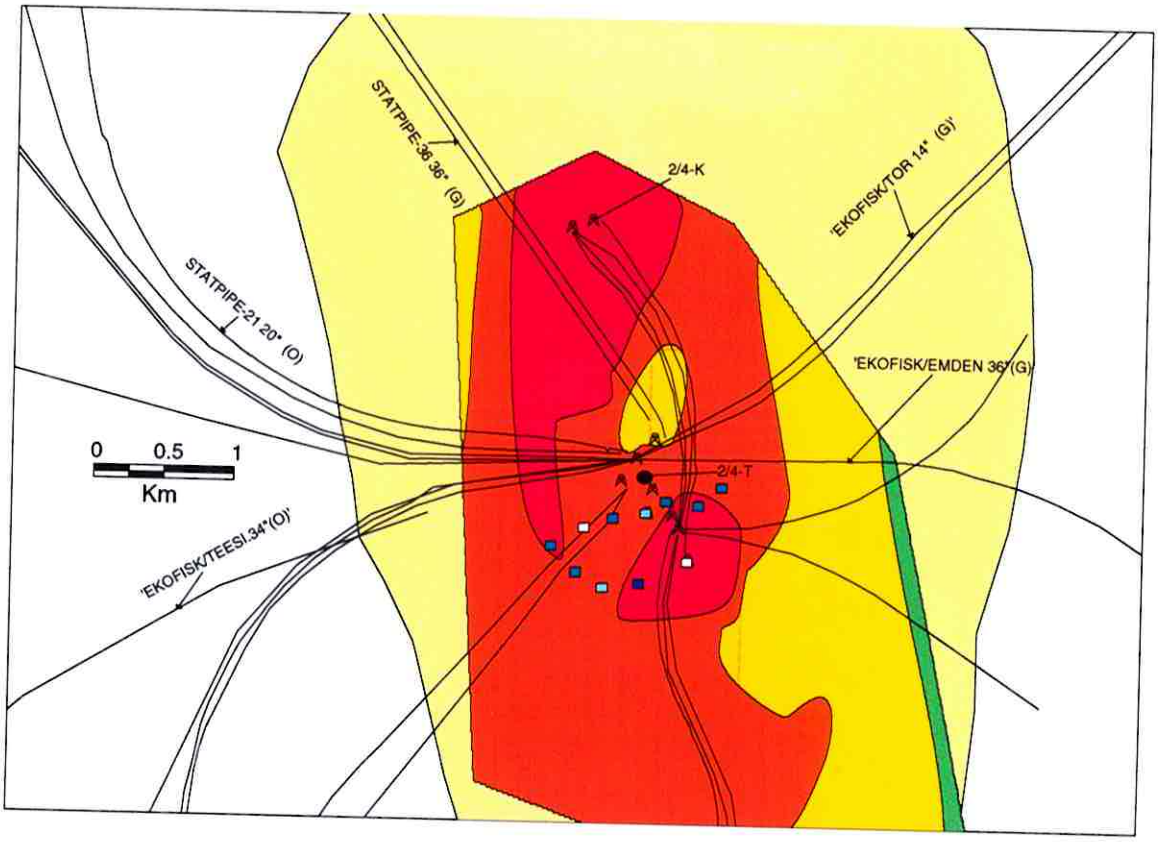

Figure 3.41: *Reef Alternative 5(Tank), phase 2, for habitat protection*

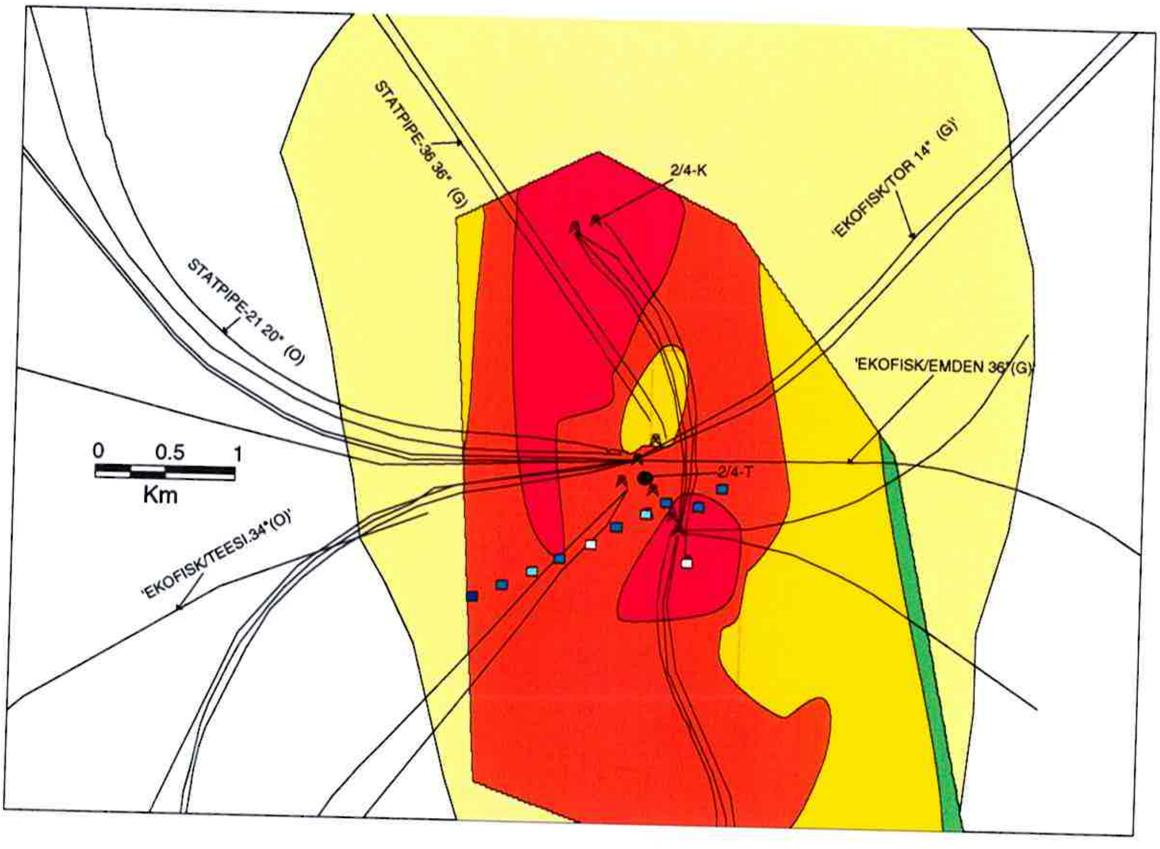

Figure 3.42: *Reef Alternative 5(Tank), phase 2, for fishing enhancement*

Appendix

3.2: Energy use and air emissions calculations

Introduction

This is a high level analysis based on high level operational planning and inconstant data drawn from many different sources. The results must therefore be considered only as qualitative. Assumptions and a brief description of the removal operations methodology for the calculations are outlined, this is based on a costing report for the Ekofisk field commissioned by Phillips Petroleum Company Norway (PPCoN) and yet to be completed.

Assumptions for the calculations

The main assumptions presented here may serve as a framework when these calculations were implemented. The following main assumptions were made during the calculations:

- It is expected that topsides, pipelines and drill cuttings are removed prior any operational activity for the reef creation.
- Vessels will transfer between installation during the operations. The use of energy and air emissions under transportation is not calculated for, since this is assumed to be the same for all six alternatives.
- The energy calculations for offshore decommissioning activity are based on typical industry experience. It is important to appreciate that weather and technical problems could result in increased operations offshore, which could result in a considerable increase in energy use and emission discharges.
- The removal of some installations like 7/11 Cod and Ekofisk 2/4-K will require more detailed planning than for a standard platform. For simplicity in the calculations, they are assumed to be a standard platform.

Methodology for the calculations

An overall summary of the energy consumed and emissions generated from the six Ekoreef alternatives will be pieced together from modules describing the operations. The modules consist of:

- A generic mobilisation and demobilisation for the SSCV, DSV and tugs energy and emissions consumption.
- A cutting bellow the seabed and lifting ready for transfer of each installation using an SSCV.
- A cutting above the seabed and pull over to leave in situ.
- Transfer of an installation at the end of an SSCV crane a distance of 9.7 UK nautical miles, at a speed of 1 knot.

Energy usage will be estimated in GJ, calculated from fuel consumption for each option, and the emission to atmosphere by way of CO_2, NO_x, SO_x and HC. Typical platforms are used to represent the different platforms in the field these are as follows:

- 2/4-B, a 12 leg platform
- 2/4-D, an 8 leg platform
- 2/4-P, a 4 leg platform

The emissions generated by marine diesel engines are generally oxygen (O_2), nitrogen (NO), carbon dioxide (CO_2), carbon monoxide (CO), oxides of nitrogen (NO_x), oxides of sulphur (SO_x), hydrocarbons (HC) and particles. To simplify the discussion, the calculated NO_x values are converted to CO_2 values, by the conversion factor, which is given to be 40 in the literature (Auris 1995).

The modules are illustrated in detailed Tables and Schedules in the costing report (not attached). Summary of the calculations from this report are presented in Tables 3.15 and 3.16, for the energy use and air emission, respectively. The values from Tables 3.15 - 3.16 are summed up in Table 3.10 and are discussed in a wider context under Section 3.5.5: *Environmental impact of reef design*, and in Report 4: *Impacts and waste management*.

***Table 3.15**: Energy consumption associated with the proposed reef creation Alternatives.*

	Alternative 1				Alternative 2				Alternative 3			
Mobilisation and demobilisation	Type of vessel				Type of vessel				Type of vessel			
	Diving/RC	Lifting	Barge/Tu	Total Sum	Diving/RC	Lifting	Barge/Tu	Total Sum	Diving/RC	Lifting	Barge/Tu	Total Sum
Number of vessels used	3	1	4									
Energy use (from Table A8)	3388	14008	5172									
Sum energy use	10164	14008	20688	44860	Phase 1 and Phase 2			89720	Phase 1 and Phase 2			89720
Cutting and lift operations	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms removed	5	5	1		7	6	3		7	4	1	
Energy use (from Table A1,3,5)	7590	5597	4357		7590	5597	4357		7590	5597	4357	
Sum energy use	37950	27985	4357	70292	53130	33582	13071	99783	53130	22388	4357	79875
Pull over and Leave in situ	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms toppled	3	5	5		2	1	4		3	4	5	
Energy use (from Table A2,4,6)	8818	4287	2693		8818	4287	2693		8818	4287	2693	
Sum energy use	26454	21435	13465	61354	17636	4287	10772	32695	26454	17148	13465	57067
Transportation	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms transported	5	5	1		7	6	3		7	4	1	
Energy use (from Table A7)	3262	3262	3262		3262	3262	3262		3262	3262	3262	
Sum energy use	16310	16310	3262	35882	22834	19572	9786	52192	22834	13048	3262	39144
Total energy use (GJ)				212388				274390				265806

	Alternative 4				Alternative 5				Alternative 6			
Mobilisation and demobilisation	Type of vessel				Type of vessel				Type of vessel			
	Diving/RC	Lifting	Barge/Tu	Total Sum	Diving/RC	Lifting	Barge/Tu	Total Sum	Diving/RC	Lifting	Barge/Tu	Total Sum
Number of vessels used												
Energy use (from Table A8)												
Sum energy use	Phase 1 and Phase 2			89720	Phase 1 and Phase 2			89720				44860
Cutting and lift operations	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms removed	7	8	7		7	5	5					
Energy use (from Table A1,3,5)	7590	5597	4357		7590	5597	4357					
Sum energy use	53130	44776	30499	128405	53130	27985	21785	102900	No removal			
Pull over and Leave in situ	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms toppled	2	0	0		3	3	1		8	10	6	
Energy use (from Table A2,4,6)	8818	4287	2693		8818	4287	2693		8818	4287	2693	
Sum energy use	17636	0	0	17636	26454	12861	2693	42008	70544	42870	16158	129572
Transportation	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms transported	7	8	7		7	5	5					
Energy use (from Table A7)	3262	3262	3262		3262	3262	3262					
Sum energy use	22834	26096	22834	71764	22834	16310	16310	55454	No transportation			
Total energy use (GJ)				307525				290082				174432

***Table 3.16a**: Air emissions associated with Alternatives 1 - 3.*

	Alternative 1				Alternative 2				Alternative 3			
Mobilisation and demobilisation	Type of vessel				Type of vessel				Type of vessel			
	Diving/R	Lifting	Barge/Tı	Total Su	Diving/R	Lifting	Barge/Tı	Total Su	Diving/R	Lifting	Barge/Tı	Total Sur
Number of vessels used	3	1	4									
CO2 (fromTableA 8)	255	1056	390									
Sum CO2	765	1056	1560	3381	Phase 1 and Phase 2			6762	Phase 1 and Phase 2			6762
Nox (from TableA 8)	5	19	7									
Conversion factor from Nox to CO2	40	40	40									
Sum Nox	600	760	1120	2480	Phase 1 and Phase 2			4960	Phase 1 and Phase 2			4960
Cutting and lift operations	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms removed	5	5	1		7	6	3		7	4	1	
CO2 (fromTable A1,3,5)	572	422	329		572	422	329		572	422	329	
Sum CO2	2860	2110	329	5299	4004	2532	987	7523	4004	1688	329	6021
Nox (from Table A1,3,5)	10	8	6		10	8	6		10	8	6	
Conversion factor from Nox to CO2	40	40	40		40	40	40		40	40	40	
Sum Nox	2000	1600	240	3840	2800	1920	720	5440	2800	1280	240	4320
Pull over and Leave in situ	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms toppled	3	5	5		2	1	4		3	4	5	
CO2 (fromTable A2,4,6)	665	323	203		665	323	203		665	323	203	
Sum CO2	1995	1615	1015	4625	1330	323	812	2465	1995	1292	1015	4302
Nox (from Table A2,4,6)	12	6	4		12	6	4		12	6	4	
Conversion factor from Nox to CO2	40	40	40		40	40	40		40	40	40	
Sum Nox	1452	1180	800	3432	968	236	640	1844	1452	944	800	3196
Transportation	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms transported	5	5	1		7	6	3		7	4	1	
CO2 (fromTable A7)	246	246	246		246	246	246		246	246	246	
Sum CO2	1230	1230	246	2706	1722	1476	738	3936	1722	984	246	2952
Nox (from Table A7)	5	5	5		5	5	5		5	5	5	
Conversion factor from Nox to CO2	40	40	40		40	40	40		40	40	40	
Sum Nox	1000	1000	200	2200	1400	1200	600	3200	1400	800	200	2400
Total air emissions (tonnes)				25763				32930				32513

Table 3.16b: *Air emissions associated with Alternatives 4 - 6.*

	Alternative 4				Alternative 5				Alternative 6			
Mobilisation and demobilisation	Type of vessel				Type of vessel				Type of vessel			
	Diving/R	Lifting	Barge/Tu	Total Su	Diving/R	Lifting	Barge/Tu	Total Su	Diving/R	Lifting	Barge/Tu	Total Sur
Number of vessels used												
CO2 (fromTableA 8)												
Sum CO2	Phase 1 and Phase 2			6762	Phase 1 and Phase 2			6762				3381
Nox (from TableA 8)												
Conversion factor from Nox to CO2												
Sum Nox	Phase 1 and Phase 2			4960	Phase 1 and Phase 2			4960				2480
Cutting and lift operations	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms removed	7	8	7		7	5	5					
CO2 (fromTable A1,3,5)	572	422	329		572	422	329					
Sum CO2	4004	3376	2303	9683	4004	2110	1645	7759				
Nox (from Table A1,3,5)	10	8	6		10	8	6		No removal			
Conversion factor from Nox to CO2	40	40	40		40	40	40					
Sum Nox	2800	2560	1680	7040	2800	1600	1200	5600				
Pull over and Leave in situ	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms toppled	2	0	0		3	3	1		8	10	6	
CO2 (fromTable A2,4,6)	665	323	203		665	323	203		665	323	203	
Sum CO2	1330	0	0	1330	1995	969	203	3167	5320	3230	1218	9768
Nox (from Table A2,4,6)	12	6	4		12	6	4		12	6	4	
Conversion factor from Nox to CO2	40	40	40		40	40	40		40	40	40	
Sum Nox	968	0	0	968	1452	708	160	2320	3872	2360	960	7192
Transportation	Type of platform (No. of legs)				Type of platform (No. of legs)				Type of platform (No. of legs)			
	12 legs	8 legs	4 legs		12 legs	8 legs	4 legs		12 legs	8 legs	4 legs	
Number of platforms transported	7	8	7		7	5	5					
CO2 (fromTable A7)	246	246	246		246	246	246					
Sum CO2	1722	1968	1722	5412	1722	1230	1230	4182				
Nox (from Table A7)	5	5	5		5	5	5		No transportation			
Conversion factor from Nox to CO2	40	40	40		40	40	40					
Sum Nox	1400	1600	1400	4400	1400	1000	1000	3400				
Total air emissions (tonnes)				36155				34750				22821