Twenty-five invertebrate taxa are listed from the Lucky Strike hydrothermal area. Four are shared with other hydrothermal vent systems on the mid-Atlantic Ridge and seven are previously undescribed new species closely associated with hydrothermal activity. Several taxa, typical of eastern Pacific vents or western Pacific back-arc hydrothermal systems (tubeworms, vesicomyid clams and alviniconchid gastropods for example), are absent. Sixty-six species have been described from this site to date. The vent communities at Lucky Strike have a sufficiently unique fauna to be considered as representing a different biogeographic hydrothermal province to those previously described (Van Dover *et al.*, 1996).

Rainbow (36° 11'N, 33° 57'W).
This site, which is at a depth of 2,300m, has about 10 groups of very active black smokers. The hydrothermal fluids have a very high particle content and temperatures (360° C), enriched in copper, nickel, zinc and cobalt. Thirty-two species have been identified at the site which is dominated by shrimps. Many of the chimneys have no animals around them (MOMAR webpage).

There is an apparent long-term stability of the vent fields in the Atlantic. Lalou *et al.*, (1995) identified numerous cycles of venting using radiometric ageing of sulphids in the TAG vent field which suggested sporadic activity spanning a period of nearly 150,000 years. Fossil examples of vent communities have also been found indicating that there were marine communities associated with active sulphide mineralisation as far back as the Lower Carboniferous, at least 350 million years ago.

At the present time there are four known vent fields in the OSPAR area. These are the Menez Gwen, Lucky Strike, Saldanha and Rainbow vents (figure 20). In the Atlantic, the hydrothermal vents are associated with the mid-Atlantic Ridge and have been reported over a range of depths. The Menez Gwen vent field (37° 51' N, 30° 02' W) to the west of the Azores is a particularly shallow example at only 850m, whereas the TAG vent field (26° 08' N, 44° 49' W) further south is at a depth of 3,650m. The most recently discovered site is the Saldanha field at 2,200m and which was first encountered in 1998. Seawater has been observed emerging directly from the seafloor rather than through chimneys at this site but further exploration of the area is needed to confirm its main characteristics.

2.5 CORAL REEFS

The existence of corals in the deep sea has been known for more than a century. Precious corals (*Corallium* spp,) solitary stony corals (for example, *Flabellum goodei* & *Desmophyllum dianthus*) and colonial corals (for example, *Solenosmilia variabilis* & *Lophelia pertusa*) have all been found at a great depth and some, such as *Lophelia*, *Madrepora*, *Desmophyllum*, and *Solenosmilia* are found world-wide (Wilson, 1979a; Gage & Tyler, 1991; Koslow & Gowlett-Holmes, 1998). This section describes reefs formed by *Lophelia pertusa* although other hard corals such as *Madrepora oculata*, *Dendrophyllia cornigera* and *Solenosmilia variabilis* may also be present.

Plate 2: *Lophelia pertusa* polyps (close-up)

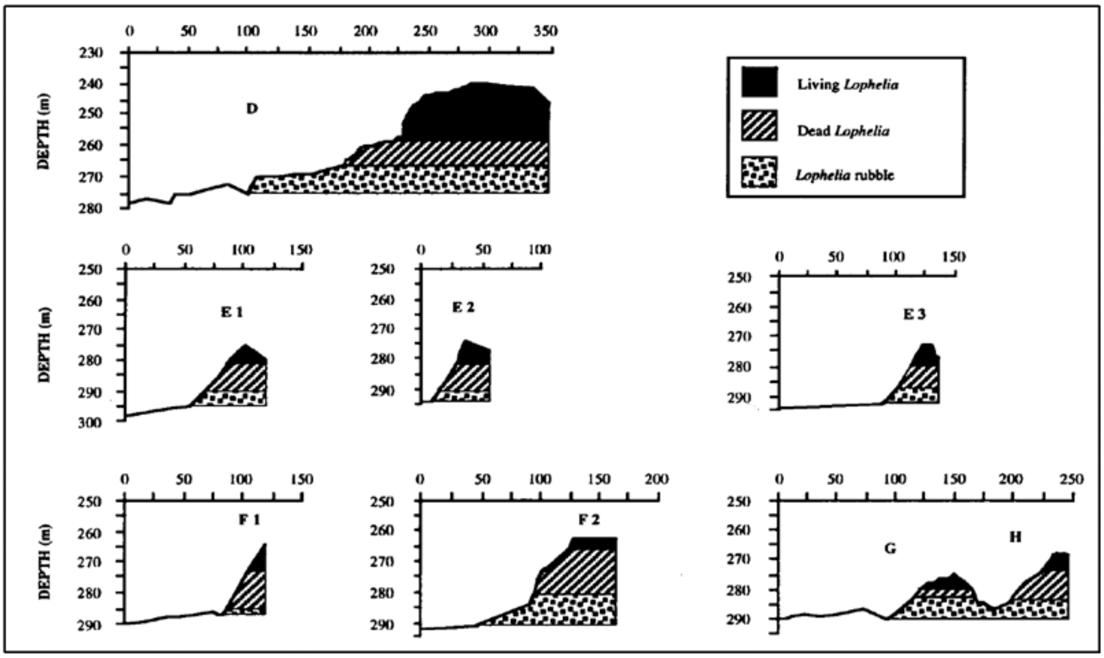
Photograph by Pal B. Mortensen and kindly donated by Jan Helge Fossa, Institute of Marine Research, Bergen, Norway. The polyps of Lophelia pertusa have nematocysts which form batteries, visible as small white grains on the tentacles. By means of the tentacles and nematocysts the corals catch animals for food. As they grow, the polyps form the typical doomshaped framework. On the external surface a mucus-like sheet is found but it is not known if the polyps have any form of communication or metabolic transport through this layer. The skeleton is repeatedly closed by walls in the bottom of the corallites, thus there is no internal contact between the individual corallites.

Colonies of Lophelia have been reported from the continental shelf, shelf slopes between 200-400m and offshore banks and troughs as well as in shallower waters in the fjords of western Norway and on the Swedish west coast. They are often found in areas where the local topography accelerates the water flow. The coral forms a hard, branched, external skeleton of calcium carbonate which protects individual polyps that extend their tentacles into the water to feed on phytoplankton, zooplankton and detritus. Because some colonies occur in areas where hydrocarbons seep into the water column from the sea-bed it has been proposed that chemotrophic bacteria thrive and provide the corals and other suspension feeders with a substantial and reliable food source but it remains unclear whether this is the case (Hovland & Thomsen, 1997; Hovland et al., 1998; Sumina & Kennedy, 1998).

Four different microhabitats of *Lophelia* colonies have been described: the smooth surface of living *Lophelia*, the detritus laden surface of dead *Lophelia*, the cavities inside dead *Lophelia* made by boring sponges, and the free space between the coral branches (Mortensen, 1995). Transects across coral structures in the Haltenbanken-Froyabanken area off the coast of Norway revealed that there was generally a basal area of *Lophelia* rubble overlain by dead *Lophelia* and then a covering of living coral (figure 21). The basal area of dead *Lophelia* was on average 7.6 times larger than that occupied by living *Lophelia*. The smallest structure was 1,500m^2 and the largest 50,600m^2.

The development of patches of the coral on the Rockall Bank was studied in the early 1970s and led to the suggestion that an initial colony, which requires a hard substrate on which to settle, gives rise to a ring of young colonies as sections break off, perhaps weakened by the activities of boring sponges or damage from fishing gear. The smaller pieces may then provide a hard surface for colonisation of subsequent colonies (Wilson, 1979b). The reports from the Rockall Bank and Bay of Biscay are of hummocks rarely more than 1m high, but much more extensive structures can develop. Those off the Norwegian coast, for example, are known to be several kilometres long and more than 20m high.

Figure 21: Examples of depth profiles of transects across coral bioherms off the coast of Norway (from Mortensen *et al.,* 1995).

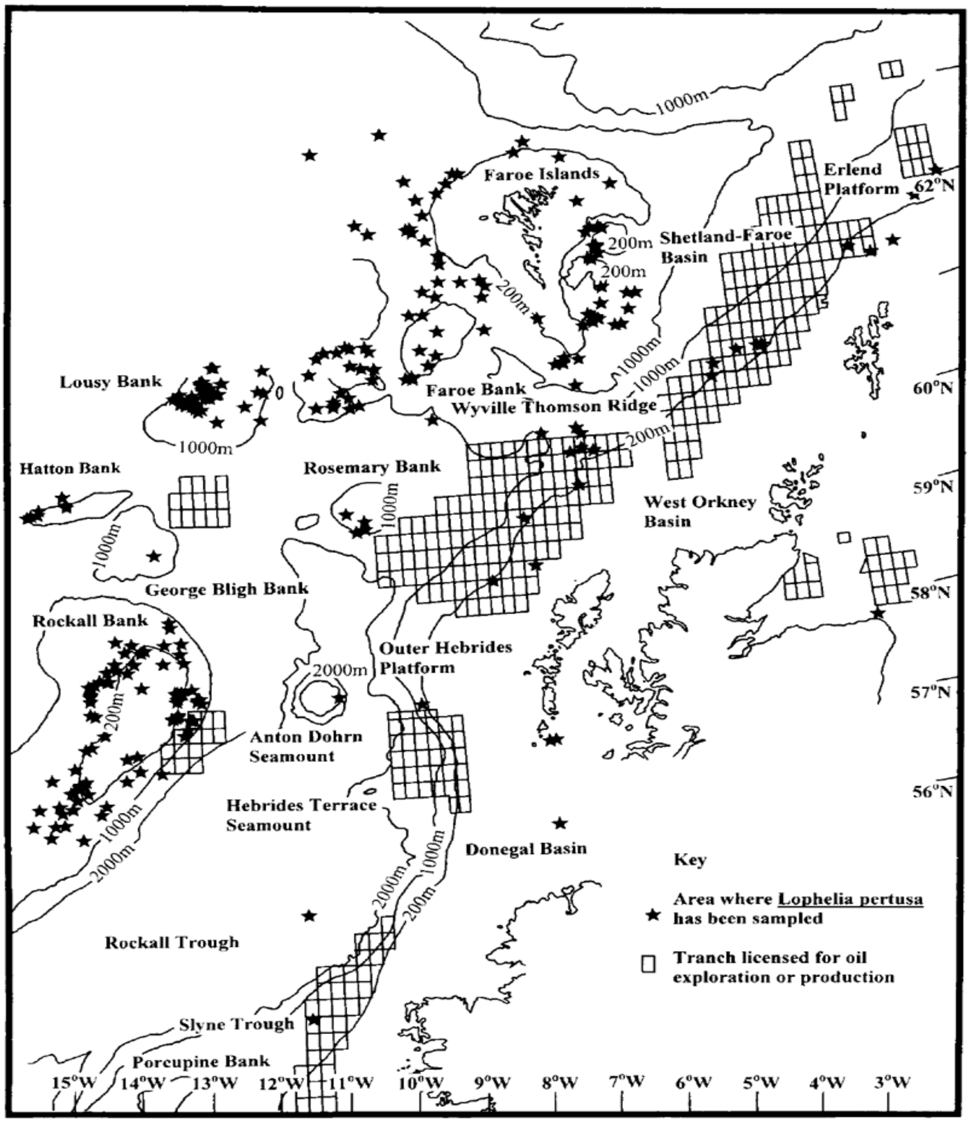


Almost all growth of the coral is thought to occur by asexual budding and to be more or less continuous while conditions are suitable. Limitations to the sizes of colonies are therefore thought to be dictated by factors such as the mechanical strength of living, growing branches, water flow through the colony and rate of weakening of the dead portions of the colonies for example as a result of the burrowing activities of clionid sponges (Wilson, 1979b). Using the growth rates of colonies on cables (average of 7.5mm/yr) as a basis for calculation, it has been estimated that the reefs on the Rockall Bank may have taken between 200-366 years to reach 1.5m height. The 15m high reefs off the Norwegian coast might be at least 2,000 years old (Mortensen *et al*, 1995). A combination of geophysical, visual, geochemical, radiocarbon and other data relating to the coral banks off mid-Norway suggest that at least some of them have been forming in the same locality for over 8,000 years (Hovland *et al.*, 1998).

2.5.1 Occurrence in the OSPAR maritime area

L.pertusa is widely distributed in the north-east Atlantic having been reported from the Bay of Biscay, Porcupine Bank, west of Ireland, Rockall Bank, north and east of the Faeroe Bank, and in Norwegian waters (Wilson, 1979). As it has been recorded from the continental shelf of the north-east Atlantic more frequently than from other parts of the world, the area may be regarded as of global significance for the species (Rogers, 1999). Some reports are of isolated or small thickets of corals, and in other cases, of extensive reefs. Hummocks of the coral up to 1m high are fairly common on the flanks of Rockall Bank between 130 and 400m for example, thickets 6-8m across have been mapped in the Bay of Biscay, and extensive reefs, some up to 31m high have been reported at depths between 200-400m off the Norwegian continental shelf (Fossa *et al.,* 1999; Mortensen *et al,* 1995). Trawl haul records and information on fisheries charts show that the coral was present on the Scottish continental shelf and slope, north and west of Shetland and Orkney, on the shelf edge west of the Outer Hebrides and on various offshore banks (figure 22). The patches around the Rockall Bank tended to occur mostly within the zone of the slope that has been furrowed by icebergs. New records for *Lophelia* and other hard corals continue to be made as deep sea surveys extend into new areas or look at previously mapped sections of the sea-bed in more detail. It may also be that *Lophelia* was more extensive with colonies being lost due to naturally occurring slumps and erosion.

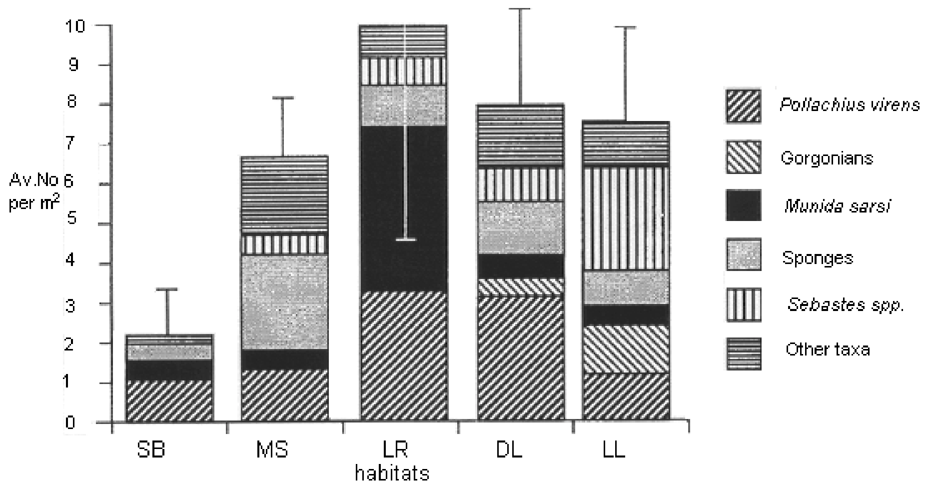
Figure 22: Areas where *L.pertusa* has been sampled and approximate position of licensed areas for oil exploration and production to the north and west of the UK (from Rogers, 1999)



2.5.2 Coral reef communities

The coral provides a three-dimensional structure and variety of microhabitats that provide shelter and a surface for attachment to other species. Boring sponges, anemones, bryozoans, gorgonians, polychaetes, barnacles and bivalves have all been recorded within and among the corals (Wilson, 1979b; Mortensen *et al.*, 1995). Other hard corals such as *Madrepora oculata* and *Solenosmilia variabilis* may also be present and in surveys in the Porcupine Bight living *M.oculata* was in fact more abundant than living *L.pertusa*. Mobile species also appear to be attracted to the coral reefs. Dense aggregations of the redfish *Sebastes viviparus* have been observed on the *Lophelia* reefs off the coast of Norway in May, many of which were gravid females with expanded bellies raising the possibility that the reefs may be used as spawning or nursery areas by some fish. Longline fishing catches showed catches of *Sebastes marinus*, *Molva molva* and *Brosme brosme* significantly higher in coral areas than on the surrounding sea-bed (Fossa *et al.*, 1999).

Figure 23: Average density of individuals/colonies in different habitats around *Lophelia* (Mortensen *et al.*, 1995)



About 886 species have been recorded living on or in *Lophelia* reefs in the north-east Atlantic and although much remains to be learnt, the diversity seems to be of a similar order of magnitude to that of some shallow water tropical coral reefs although different groups dominate the fauna (Rogers, 1999). Nearly 300 invertebrate species have been collected around *Lophelia* reefs near the Faroes (Jensen & Frederiksen, 1992) and 36 taxa represented in samples in and around the *Lophelia* reefs off the coast of Norway five of which were only found on the coral structures (Mortensen *et al.*, 1995). Sponges dominated the sessile fauna on the stones below the coral structures and the squat lobster *Munida sarsi* occurred in high densities on the *Lophelia* rubble (figure 23). The fish fauna was dominated by saithe *Pollachius virens*) and redfish (*Sebastes* spp.) with highest densities of saithe on the rubble and dead areas feeding on the bottom, but redfish most common in the living *Lophelia* zone (up to 8/10 per m^2) and only a few on the surrounding soft sea-bed. It has been suggested that the squat lobsters are probably and important source of food for benthic fish species living near the corals whereas the redfish probably use them as shelter and feeding place. Saithe are thought to be a temporary member of the reef fauna.

The branching structure of dead coral under the living coral also provides a surface for attachment and consequently dead coral debris on the reefs supports a rich fauna of sponges, anemones and bryozoans including *Pyripora catenularia*, *Porella compressa, Diplosolen obelium*, calcareous polychaetes such as *Serpula vermicularis*, *Hydoirdes* sp. and *Filograna* sp. brachiopods including *Crania anomala*, *Terebratual retusa* and *Macandrevia cranium*, bivalves and the echinoids *Cidaris cidaris* and *Echinus* species. It also provides shelter for scavengers such as *Munida rugosa* and *Ebalia tuberosa* (Wilson, 1979b; Suminda & Kennedy, 1998).

2.5.3 Conservation issues

The delicate structure and slow growth rate of *Lophelia* make these coral reefs particularly vulnerable to physical damage. Bottom trawling, where heavy fishing gear is dragged along the sea-bed is therefore a major concern. Damage to reefs from the activity of trawlers has been documented off the coast of Norway where there have also been many anecdotal reports of trawlers using their gear, wires, chains and trawl doors to crush the corals to clear the area before fishing starts. (Fossa *et al.,* 1999). There are also reports of coral being brought up in trawls off the Rockall Bank (Wilson, 1979). It has been suggested new colonies can grow from broken fragments but this may be countered by suspension of sediments by trawling activity which can smother and affect feeding as well as potentially inhibiting the settlement of larvae and therefore the colonisation of previous disturbed areas (Rogers, 1999).

The advent of oil exploration and production in deep sea areas where *Lophelia* is known to occur is another concern. The effects of drill cuttings, water-based and synthetic drilling muds, and the variety of chemicals and contaminants including dissolved and dispersed oil which are known to enter the environment around offshore oil operations, may have lethal and sublethal effects on corals (Rogers, 1999) This is particularly relevant in the north-east Atlantic as oil exploration is taking place in areas where *L.pertusa* is known to occur.

Because of the slow growth rate of the coral, recovery from such impacts could take hundreds of years even if areas remain undisturbed after the initial damage.

Plate 3: Undamaged

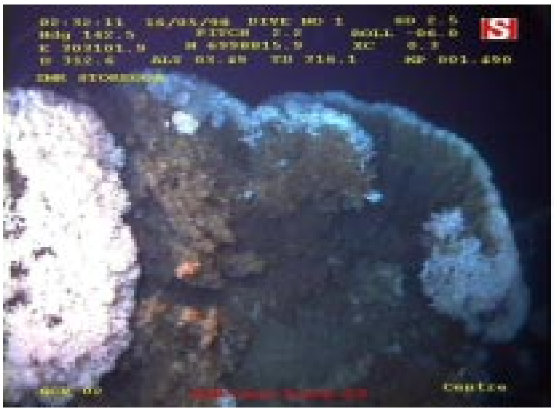


Plate 4: Damaged

Photographs by Pal B. Mortensen and published with kind permission of Jan Helge Fossa, Institute of Marine Research, Bergen plate 3: Video photograph from the Norwegian continental shelf north of Haltenbanken (17 May 1999). Plate 4: Video photograph from the Norwegian continental break at 220m depth (16 May 1998), showing a barren landscape with spread, crushed remains of Lophelia-corals. This is an area that is subject to considerable bottom trawling. A track can be seen stretching from bottom-left to up-right of the photograph, indicating the path of a trawl.

2.5.4 Conservation actions

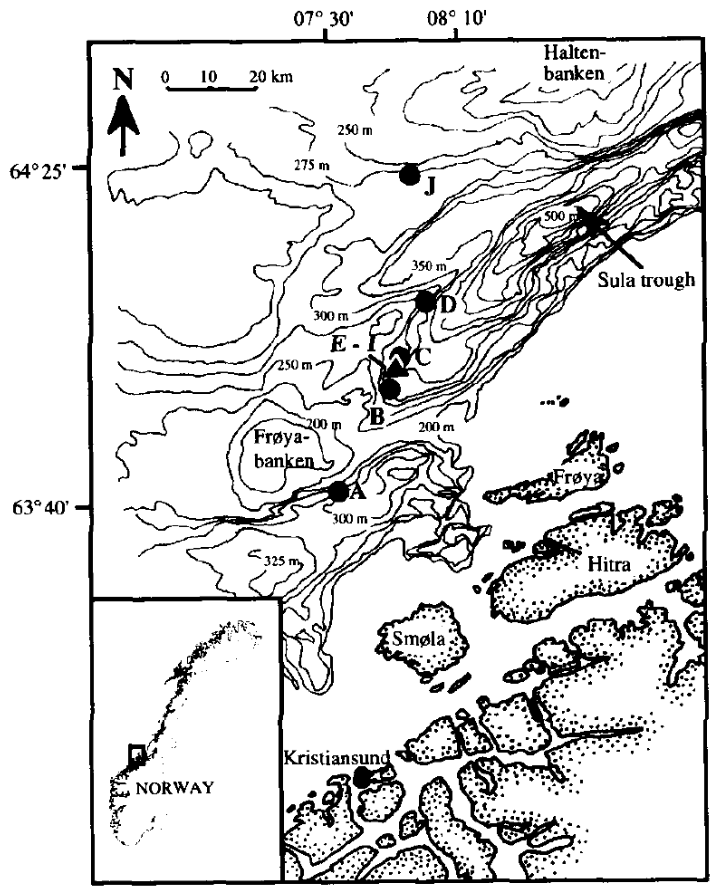
Conservation of deep sea coral reefs requires a range of types of action. Like shallow water reefs, the protection of defined areas will be a valuable tool as this can limit the direct impacts on the reef structures. This type of action has been taken by the Norwegian government which established a protected area around the Sula Ridge reefs in 1999. More general measures have also been introduced prohibiting all intentional destruction of coral reefs wherever they occur in Norwegian waters (WWF, 1999).

Indirect measures to safeguard water quality and sedimentation around *Lophelia* reefs is another important action that should be taken. This is particularly important in the areas where offshore oil exploration and production activities are proposed or already underway. If stringent standards cannot be achieved, the most appropriate course of action may be to prohibit or close down such operations.

The Sula Ridge

This site lies off the west coast of mid-Norway in a trough between the Froya Bank to the south-west and the Halten Bank to the north-east. There are numerous coral banks in depths of around 300m with the reef complex about 13km long and the largest reefs 35m high and 700m wide. The site is believed to have the best developed deep-water coral reefs in the north-east Atlantic and WWF has, therefore, proposed it as a potential MPA (WWF, 1999). In 1999 the Norwegian government gave specific protection to the coral reefs in this area.

Figure 24: Map of the Haltenbanken-Froyabanken area with coral areas investigated by Mortensen *et al.*, 1995)



2.6 FRONTS

Fronts are distinctive oceanographic features that mark the boundaries between water bodies with different characteristics. They are lateral zones above or below which there is localised and sometimes vigorous vertical movement of water. Fronts can form at salinity boundaries or where there are temperature differences between two water masses. They may also be caused by topographic features both above and below the surface. The best known fronts are tidal fronts, shelf-break and upwelling fronts, and estuarine fronts which form in coastal areas but deep sea fronts, which form in the open ocean, have also been described (Owen, 1981). Where fronts are vigorous for their size or meet an obstacle, flow becomes unstable and frontal meanders may pinch off and become eddies (see section 2.7).

Fronts occur on a number of scales. They may only be a few meters in extent and persist for hours or, at the other extreme, they may extend for thousands of kilometres and persist for years. The temperature differences which cause tidal fronts are related to the amount of mixing that takes place within coastal and oceanic waters. Coastal waters are greatly influenced by tides and this, combined with their shallow nature, mixes the system. In oceanic waters where tidal stirring is weak, the water column is poorly mixed so during the summer months the upper