Survey of Active Acoustic Monitoring (AAM) Technologies

Volume IV: E&P Environments and Marine Mammals

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Defence R&D Canada – Atlantic

External Client Report
DRDC Atlantic ECR 2010-043
March 2010

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This report has been completed for International Association of Oil and Gas Producers (OGP) under contract JIP22 08-06.

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Abstract

Under the Exploration and Production (E&P) Sound and Marine Life Programme, a research study was carried out on the feasibility of the Active Acoustic Monitoring (AAM) of marine mammals. The purpose of such monitoring would be to detect marine mammals in those ocean areas where E&P activities are being conducted, in order to allow due diligence in mitigating any potential impact of these E&P operations. The study did not include any direct experimentation.

The AAM study encompassed multiple work components. First, the problem domain was delineated in an overview of offshore E&P activities and of the ocean environments in which they are conducted. To make the analysis more concrete, six specific ocean areas of relevance to E&P were selected and their properties described. Next, the potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

This report (Volume IV) provides a description of six environments relevant to E&P Operations with unique acoustic characteristics. The acoustic description is included for each environment. In addition, a survey of marine mammals including their use of the six E&P environments is included. For each species, the IUCN (International Union for Conservation of Nature) status is included as an indication of species health.

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Executive summary

Survey of Active Acoustic Monitoring (AAM) Technologies: Volume IV: E&P Environments and Marine Mammals

J. Theriault; S. Pecknold; E. MacNeil;; DRDC Atlantic ECR 2010-043; Defence R&D Canada – Atlantic; March 2010.

Background: Under the Exploration and Production (E&P) Sound and Marine Life Programme, a research study was carried out on the feasibility of the Active Acoustic Monitoring (AAM) of marine mammals. The purpose of such monitoring would be to detect marine mammals in those ocean areas where E&P activities are being conducted, in order to allow due diligence in mitigating any potential impact of these E&P operations. The study did not include any direct experimentation.

Results: The AAM study encompassed multiple work components. First, the problem domain was delineated in an overview of offshore E&P activities and of the ocean environments in which they are conducted. To make the analysis more concrete, six specific ocean areas of relevance to E&P were selected and their properties described. Next, the potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

This report (Volume IV) provides a description of six environments relevant to E&P Operations with unique acoustic characteristics. The acoustic description is included for each environment. In addition, a survey of marine mammals including their use of the six E&P environments is included. For each species, the IUCN (International Union for Conservation of Nature) status is included as an indication of species health.

Significance: The study documents the feasibility of using AAM technologies for mitigating potential impacts of E&P acoustic emissions on marine mammals. There exist technologies that could provide a basis for actively detecting marine mammals between 500 and 1000 m. This Volume provides a critical description of the acoustic environments and the species that may be encountered.

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1 Introduction

1.1 Background

The International Association of Oil and Gas Producers (OGP) established the Exploration and Production (E&P) Sound and Marine Life Programme as an industry research fund supporting research into sound produced during E&P activities and its effect on marine life.

The JIP (Joint Industry Programme) has funded a proposal by Defence R&D Canada Atlantic, in partnership with Akoostix Inc., to deliver this study which has completed a review and inventory of current active acoustic methods and technologies and has identified potential further development areas for the detection of marine mammals during E&P activities offshore. The study has been approached as a three phase project; during the first phase background information was gathered on E&P activities / environments and a general assessment was done on the performance capabilities of active acoustic technology. In the second phase a survey of manufacturers of active systems was conducted. During the third phase these survey responses were evaluated for suitability of use in monitoring marine mammals at sea during E&P activities and recommendations were made on further development areas.

The study proposal details are contained in response to Request for Proposals JIP08-05.

1.2 Document Objective and Structure

This report is Volume IV (of five volumes) of the final report under contract JIP08-05.

- Volume I contains an overview and summary of the survey and analysis. Annex B to Volume I includes a Microsoft Excel file, with the detailed responses from each of the system suppliers, along with the evaluation.

- Volume II is the complete contract proposal.

- Volume III is the complete sub-contract report from Canadian Seabed Research on E&P Operations.

- Volume IV (this report) is a detailed description of six chosen E&P environments and the marine mammal species expected in those environments.

- Volume V is a detailed analysis of the factors affecting the performance of an AAM system.

2 E&P Environments

The environment has a major impact on the potential performance of an AAM system and has implications on the type of AAM system that could be used. The water depth, water column conditions (including surface and bottom) and the type of marine mammals present all impact system performance and are highly variable between environments. Even within a given environment there may be large variations in marine mammals and conditions, for instance due to changing seasons or weather. The impact of environmentally related factors on system performance is investigated in detail in the potential performance assessment (Volume V).

Due to the broad range of environments in which E&P activities are conducted, the approach was taken to generally characterize a small number of environments that represent a cross section of relevant areas.

The first step taken was to identify general areas/regions with a significant number of offshore developments. A number of well established areas were identified, such as the Gulf of Mexico and the UK Continental Shelf [2]. In well-established areas much of the O&G resources have been developed and new projects are typically in harder to develop areas, such as very deep water or more remote, harsher environmental areas. Numerous other areas were also identified as having a significant number of developments, including the West Coast of Africa, Barents Sea, Brazil, Indonesia, South China Sea, Atlantic Canada and North West Bank of Australia [2].

In addition to areas with existing offshore developments, consideration was also given to areas which may be future development areas. The assessment of world petroleum reserves by the United States Geological Survey estimates that the former Soviet Union and the Middle East / North Africa region contain the bulk of the world's undiscovered O&G resources [3]. In the assessment a number of offshore areas were indicated as potential locations of significant offshore resources, these include the West Coast of Africa, offshore Brazil, East Coast of Greenland, West Siberian Basin, Caspian Sea, Persian Gulf, and North Sea. The assessment also notes that a significant portion of undiscovered O&G resources are offshore, in water depths out to 4000 m.

As previously mentioned, within each of the environments identified above there are large variations in water depth, water column conditions and marine mammals. To complete a detailed assessment of the performance of each of the surveyed AAM systems in each of these environments, the specific environmental parameters would be required (e.g. Water depth, sound-speed profile, bottom type). To determine these environmental parameters a specific location and a specific time of year would need to be selected. For the general evaluation being conducted under this study it was not practical to select individual locations and times within each environment. The approach taken was to select one water depth for each environment and to provide a general evaluation of AAM performance for each environment.

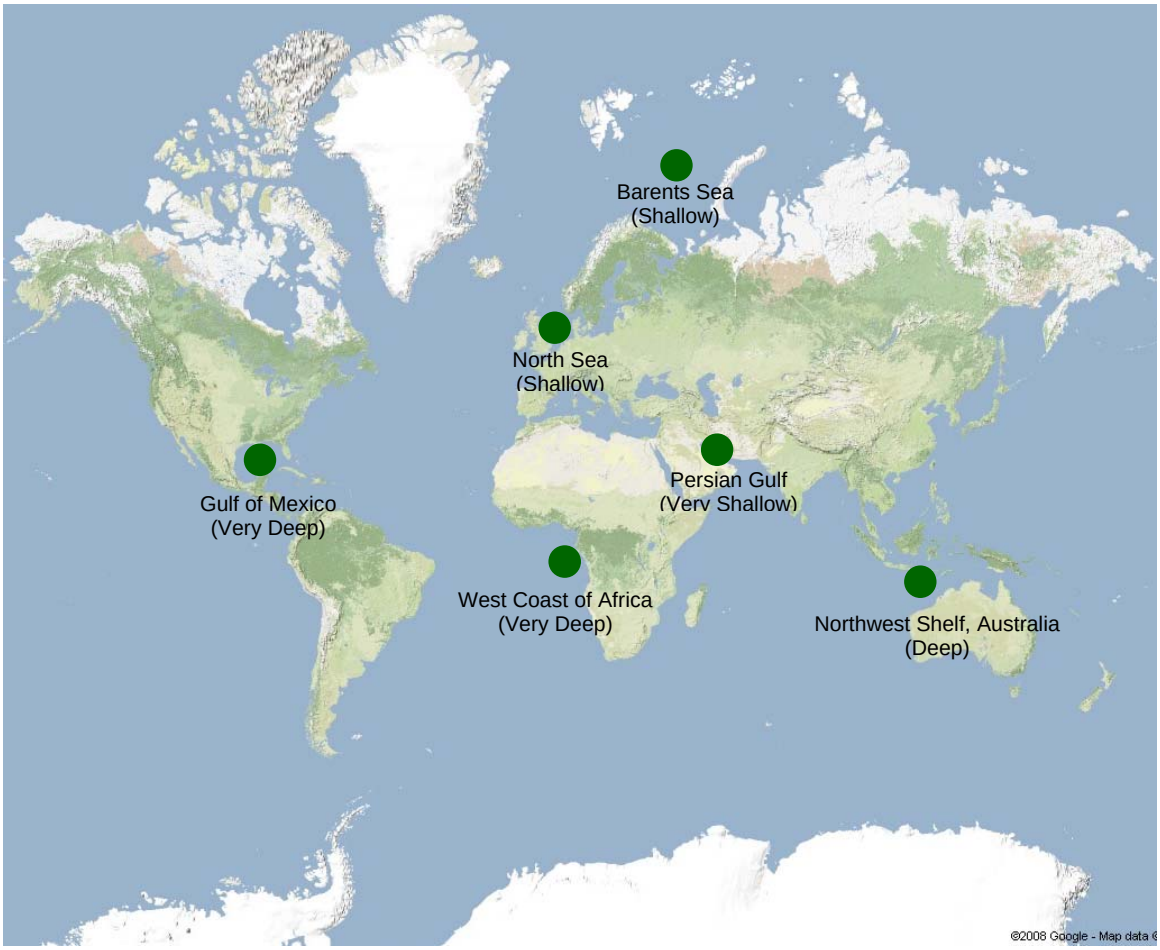


Figure 1: World Map showing locations for Six O&G Relevant Environments (Water depths defined as Very Shallow (<100m), Shallow (100-400 m), Deep (1000-2000 m), and Very Deep (> 2000 m).)

This annex contains the rough data collected on the six environments of interest to this report. Information on typical bottom properties and bathymetry is given along with water column temperature and salinity based on climatological data for each season. The climatological data is taken from the World Ocean Atlas [7] [8]. Bathymetry is from the ETOPO5 data set [9]. The bathymetry and temperature/salinity data is presented using the Ocean Data View (ODV) software [10].

Table 1: E&P Environment Descriptions

#	Area	Water Depth
S1	Arctic: Barents Sea	200m
S2	Gulf of Mexico	2000m
S3	North Sea	200m
S4	West Coast of Africa (offshore Nigeria or Angola)	2000m
S5	Northwest Shelf, Australia	1000m
S6	Persian Gulf	50m

2.1 Arctic: Barents Sea

The Barents Sea is characterized by basins of 300 to 500 m depth running in the northeast to southwest direction, and some shallower banks of 50 to 100 m depth. The bedrock composition shows a great deal of variation, described in detail in [11], separated from the upper unconsolidated and semi-consolidated glacial sediment depositions by an upper regional erosional surface. The thickness of the glacial deposits varies from 15 m in the north to several hundred m along the continental margin [11] Average sediment sound speeds are 1470 m/s at the surface and 1800 m/s in the lower part of the sediment. More details for the upper part of the sediment are available in [12]. The southern region bedrock consists primarily of shales and claystones and clay- and siltstones, with sound speeds of 2.1-3.5 and 1.8-2.8 km/s respectively, and shear speeds of 0.6-1.8 and 0.4 -1.2 km/s.

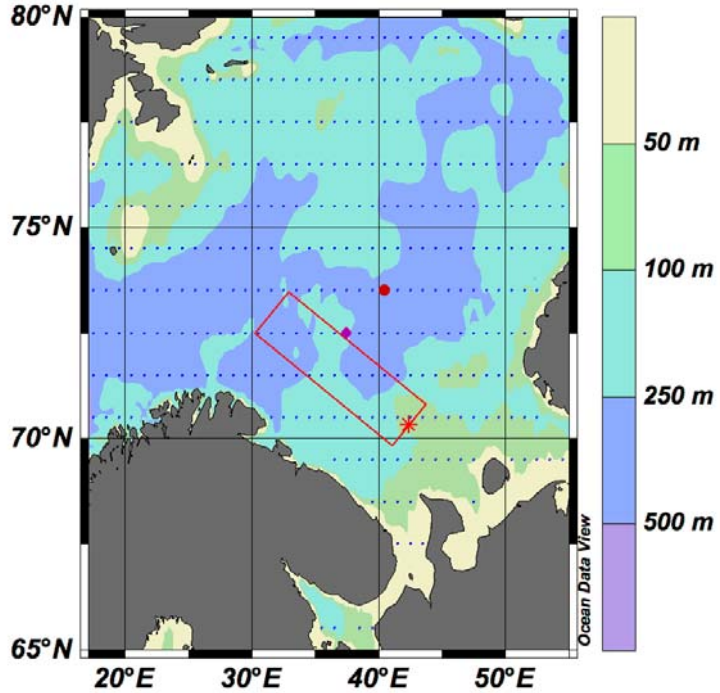
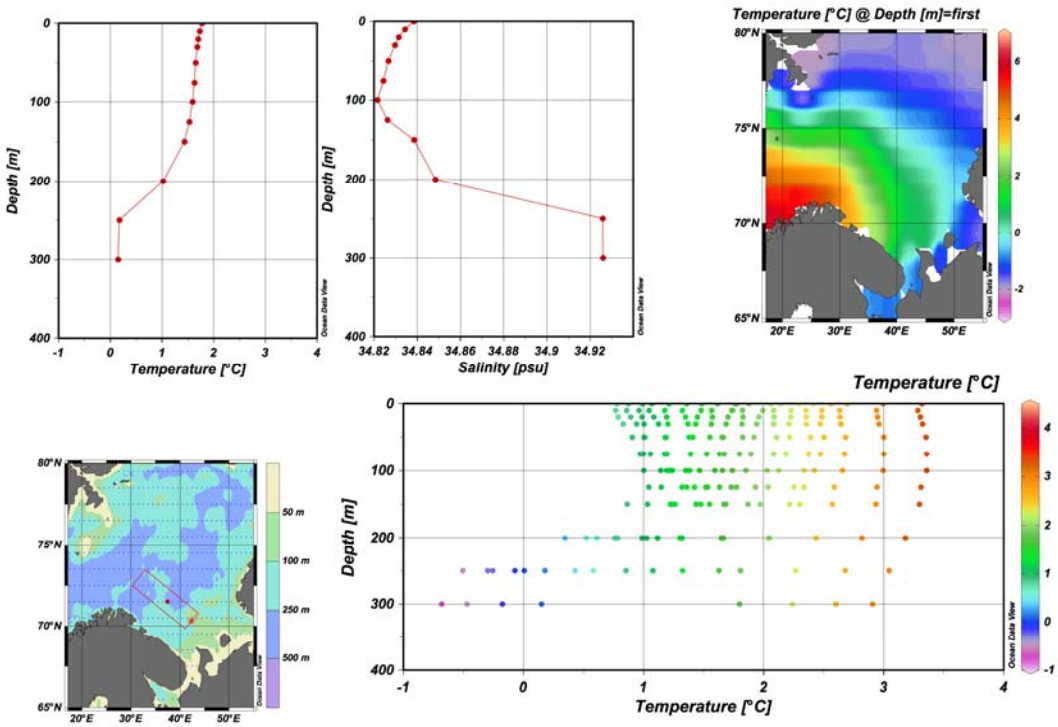


Figure 2: Barents Sea bathymetry. The red box indicates the area selected as representative. (ODV).

There are three main types of water masses in the Barents Sea: Warm, salty Atlantic water (temperature >3°C, salinity>35) from the North Atlantic drift, cold Arctic water (temperature <0°C, salinity<35) from the north, and warm, but not very salty coastal water (temperature >3°C, salinity<34,7). Between the Atlantic and Polar waters, a front called the Polar Front is formed. In the western parts of the sea (close to Bear Island), this front is determined by the bottom topography and is therefore relatively sharp and stable from year to year, while in the east (towards Novaya Zemlya), it can be quite diffuse and its position can vary between years. The sound speed profile will therefore change considerably depending on season and location. Examples have been selected from the World Ocean Atlas for each season in the location 37.5° E, 71.5° N. Figures 3 through 6 show climatological temperature and salinity information for each season in the Barents Sea.



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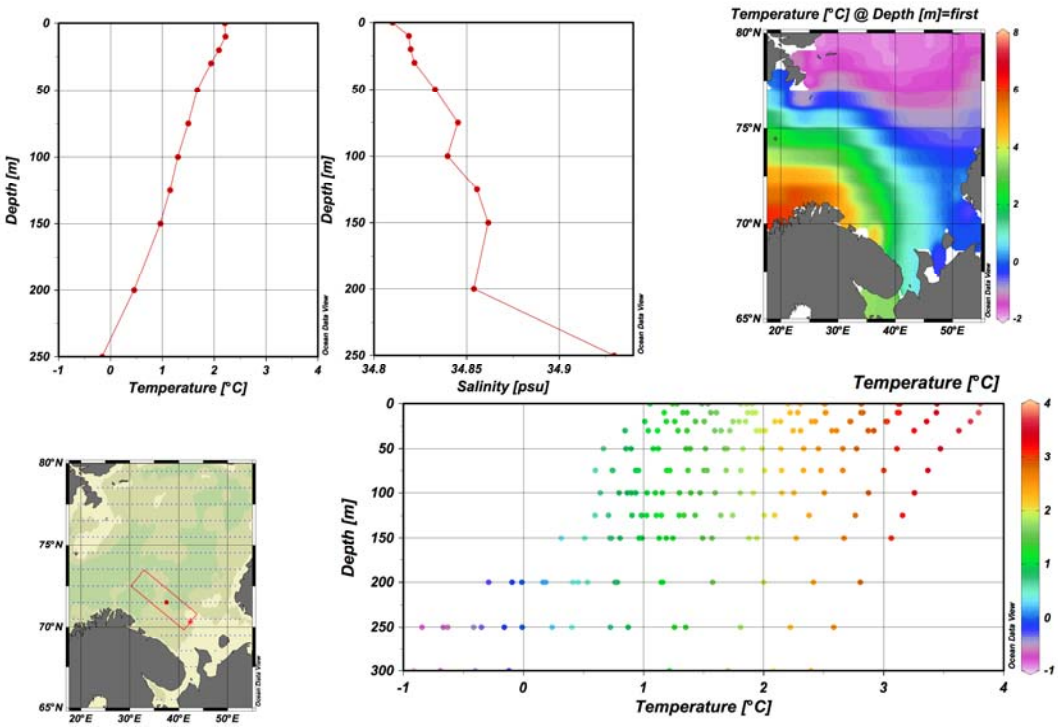

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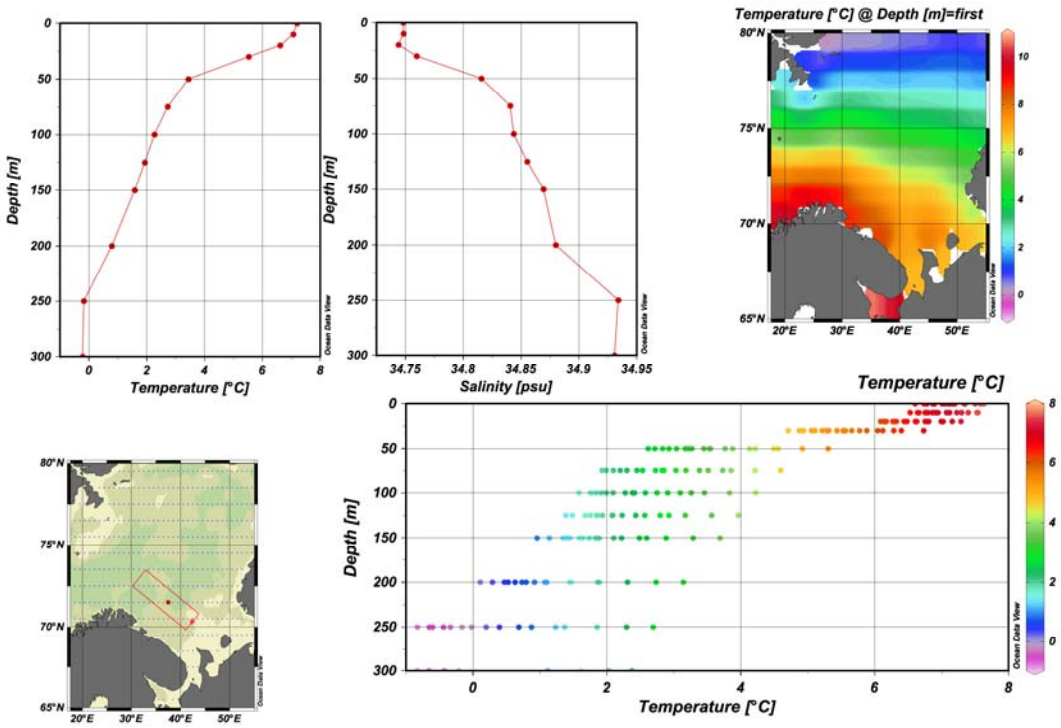

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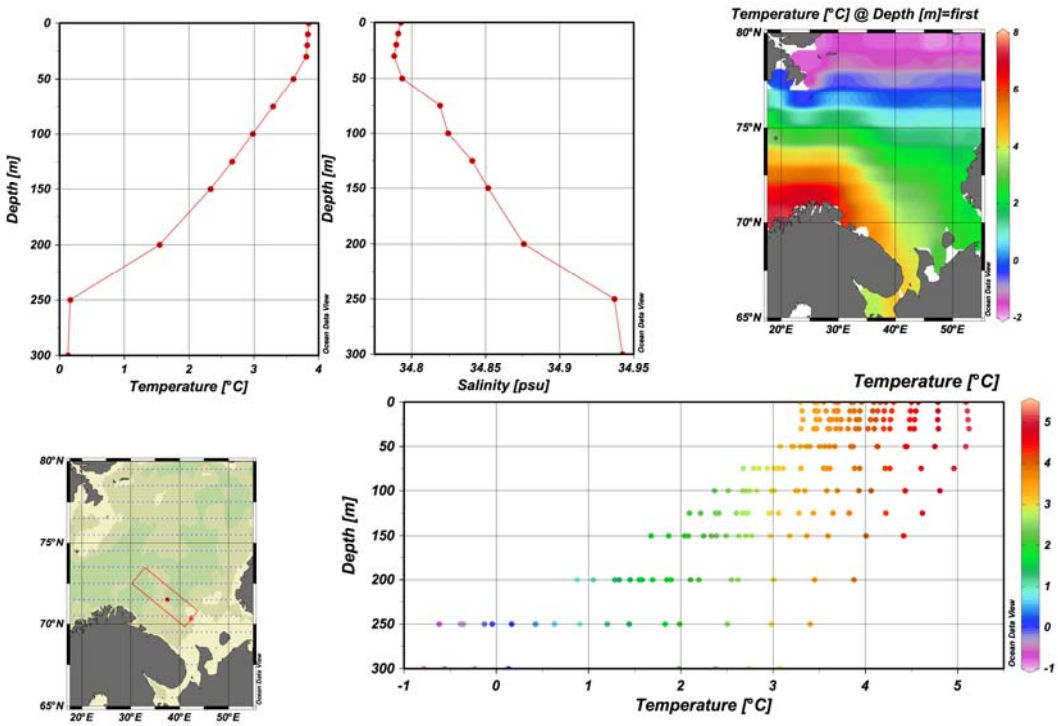

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Table 2: Barents Sea representative seasonal climatology: temperature and salinity.

	Temperature [°C]				Salinity [psu]			
Depth [m]	Winter	Spring	Summer	Fall	Spring	Spring	Summer	Fall
0	1.78	2.2	7.2	3.85	34.84	34.81	34.75	34.79
10	1.73	2.22	7.07	3.83	34.83	34.82	34.75	34.79
20	1.7	2.09	6.61	3.82	34.83	34.82	34.74	34.79
30	1.69	1.94	5.53	3.81	34.83	34.82	34.76	34.79
50	1.65	1.68	3.45	3.61	34.83	34.83	34.82	34.79
75	1.63	1.5	2.73	3.3	34.82	34.85	34.84	34.82
100	1.59	1.3	2.27	2.99	34.82	34.84	34.84	34.82
125	1.53	1.15	1.93	2.67	34.83	34.86	34.86	34.84
150	1.44	0.96	1.59	2.33	34.84	34.86	34.87	34.85
200	1.03	0.45	0.79	1.55	34.85	34.85	34.88	34.88
250	0.18	-0.16	-0.16	0.17	34.93	34.93	34.93	34.94
300	0.15	-0.12	-0.21	0.13	34.93	34.94	34.93	34.94

2.2 Gulf of Mexico

The geological and stratigraphic structure of the Gulf of Mexico, the bathymetry of which is shown in Figure 7, has been described in a number of sources. The information in 1) through 7) below is quoted from [13] , and is based on [14].

1) Gulf of Mexico Basin: This portion of the Gulf of Mexico contains the Sigsbee Deep and can be further divided into the continental rise, the Sigsbee Abyssal Plain, and the Mississippi Cone. Located between the Sigsbee escarpment and the Sigsbee Abyssal Plain, the continental rise is composed of sediments transported to the area from the north. The Sigsbee Abyssal Plain is a deep, flat portion of the Gulf bottom located northwest of Campeche Bank. In this relatively uniform area of the Gulf bottom, the Sigsbee Knolls and other small diapiric (salt) domes represent the only major topographical features. The Mississippi Cone is composed of soft sediment and extends southeast from the Mississippi Trough, eventually merging with other sediments of the central basin. The cone is bordered by the DeSoto Canyon to the east and the Mississippi Trough to the west, and has been described in detail by Ewing et al. [15].

2) Northeast Gulf of Mexico: Extending from just east of the Mississippi Delta near Biloxi to the eastern side of Apalachee Bay, this region of the Gulf bottom is characterized by soft sediments. To the west of the DeSoto Canyon, terrigenous (land-derived) sediments are thick and fill the remnants of the Gulf basin. In the eastern portion of the region, Mississippi-derived sediments cover the western edge of the Florida Carbonate Platform and a transition towards carbonate sediments begins. The Florida Escarpment separates the Florida Platform from the Gulf Basin and also forms the southeastern side of the DeSoto Canyon. In a region characterized by sediment deposition, the presence of the DeSoto Canyon is poorly understood. Some theories suggest that the canyon is the result of erosion caused by oceanic currents, possibly the Loop Current [16].

3) South Florida Continental Shelf and Slope: A submerged portion of the larger emergent Florida Peninsula, this region of the Gulf of Mexico extends along the coast from Apalachee Bay to the Straits of Florida and includes the Florida Keys and Dry Tortugas. A generalized progression towards carbonate sediments occurs from north to south ending in the thick carbonate sediments of the Florida Basin. Evidence suggests that this basin was at one time enclosed by a barrier reef system [17], [18], [19], [20]. In the Straits of Florida the Jordan Knoll appears to be composed of remnants from this ancient reef system. Evidence suggests that this reef may have once extended across the straits, adjoining the Florida reefs with those of northern Cuba.

4) Campeche Bank: Campeche Bank is an extensive carbonate bank located to the north of the Yucatan Peninsula [21]. The bank extends from the Yucatan Straits in the east to the Tabasco-Campeche Basin in the west and includes Arrecife Alacran. The region shows many similarities to the south Florida platform and some evidence suggests that the two ancient reef systems may have been continuous [20], [22] . Continental drift and erosional processes are both theorized to have played a role in the separation of the two geologically similar carbonate platforms.

5) Bay of Campeche: The Bay of Campeche is an isthmian embayment extending from the

western edge of Campeche Bank to the offshore regions just east of Veracruz (~96 degrees W). The Sierra Madre Oriental forms the south-southwestern border, and the associated coastal plain is similar to the Texas-Louisiana coast in the northern Gulf. The bottom topography is characterized by long ridges parallel to the exterior of the basin. Salt domes are prevalent in the region, and the upward migration of salt is theorized to be a cause of the complex bottom profiles [23]. Similar to the northern Gulf, large quantities of oil are produced here, and thick terrigenous sediments predominate.

6) Eastern Mexico Continental Shelf and Slope: Located between Veracruz to the south and the Rio Grande to the north, this geological province spans the entire eastern shore of Mexico. The Gulf bottom of the region is characterized by sediment-covered folds that parallel the shore. Apparently created by sediment-covered evaporites, evidence suggests that the folds have impeded sediment transport from the Mexican coast to the Gulf Basin [24]. As sediment cover increases from south to north, so does the relative complexity of the bottom structure.

7) Northern Gulf of Mexico: The northern Gulf of Mexico extends from Alabama to the U.S.-Mexico border. North to south, the province extends from 200 miles inland of the present day shoreline to the Sigsbee escarpment. Sediments in the region are generally thick with the greatest sediment load provided by the Mississippi River. Widespread salt deposits are present throughout the region[25, 26] and these structures act to create subsurface and emergent topographic features on the continental slope such as the Flower Garden Banks off the Texas/Louisiana coast, and the pinnacles region offshore of the Mississippi/Alabama coast.

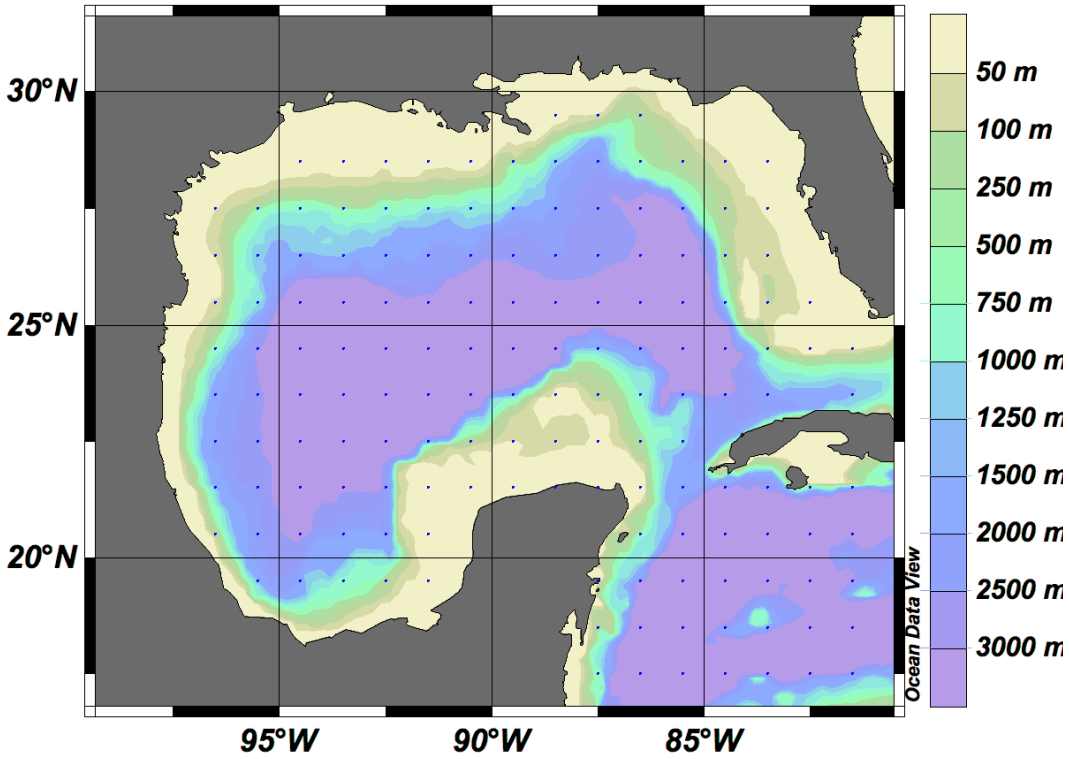

Figure 7: Gulf of Mexico bathymetry (ODV).

Given the specified depth of 2000 m, a section along 27.5° N (the continental rise from the abyssal plain to the northern Gulf) was selected as a representative area. Here, sediments are primarily clayey and silty, and sound speeds may also be affected by the presence of gas hydrates.

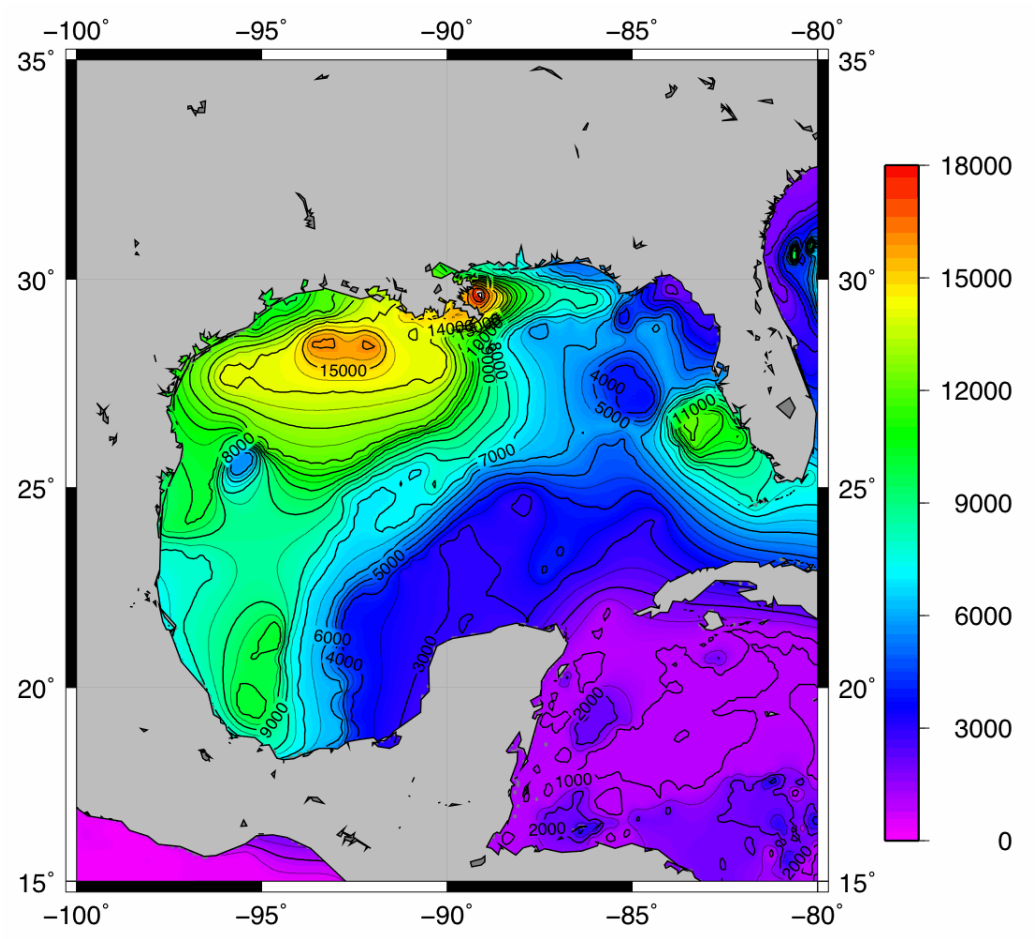

Figure 8: Gulf of Mexico sediment thickness (data from [27]).

The sediment in this area is 8 to 12 km thick (see Figure 8). Measurements of sound speed and density near the surface have values around c=1480 m/s, r=1.45 g/cm^3.

Figures 9 through 12 show representative climatological temperature and salinity information for each season in the Gulf of Mexico. The data at a representative point is summarized in Table 3.

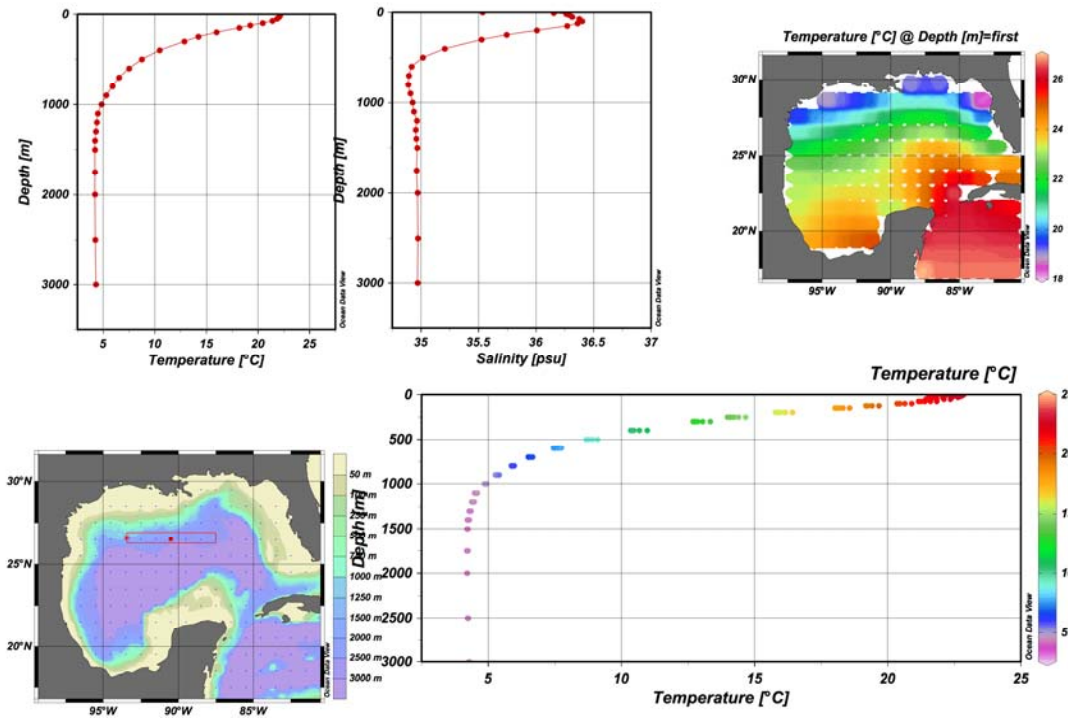

Figure 9: Clockwise from bottom left – Gulf bathymetry, average temperature profile at 90.5° W, 27.5° N, average salinity at 90.5° W, 27.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for winter (Jan-Mar). (ODV).

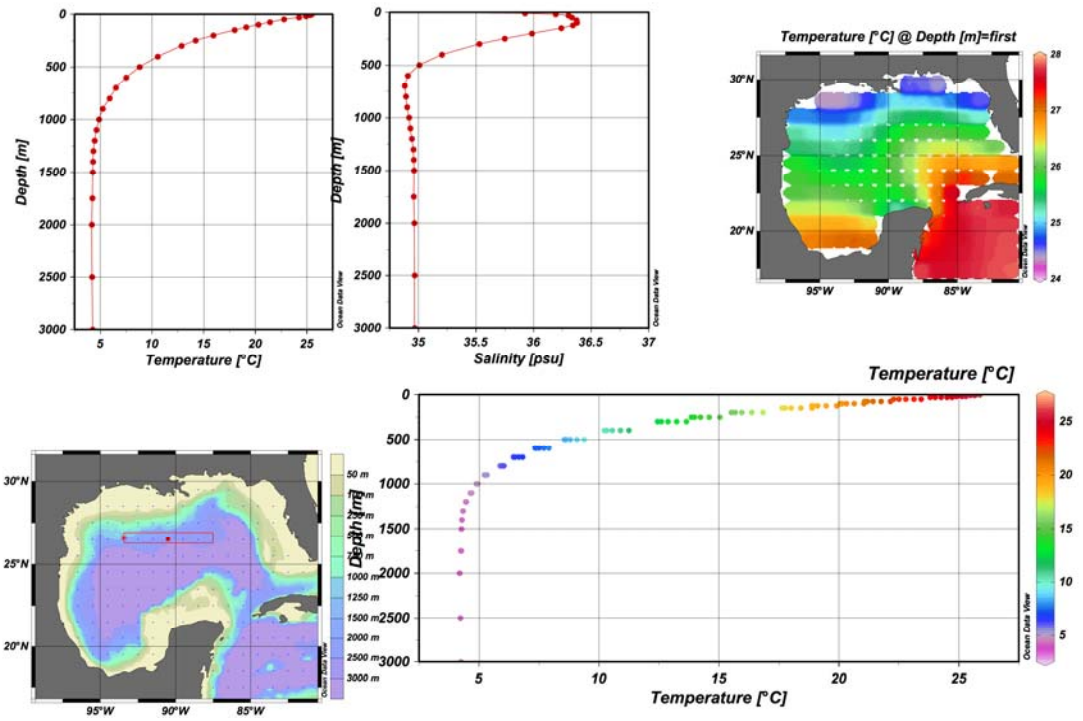

Figure 10: Clockwise from bottom left – Gulf bathymetry, average temperature profile at 90.5° W, 27.5° N, average salinity at 90.5° W, 27.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for spring (Apr-Jun). (ODV).

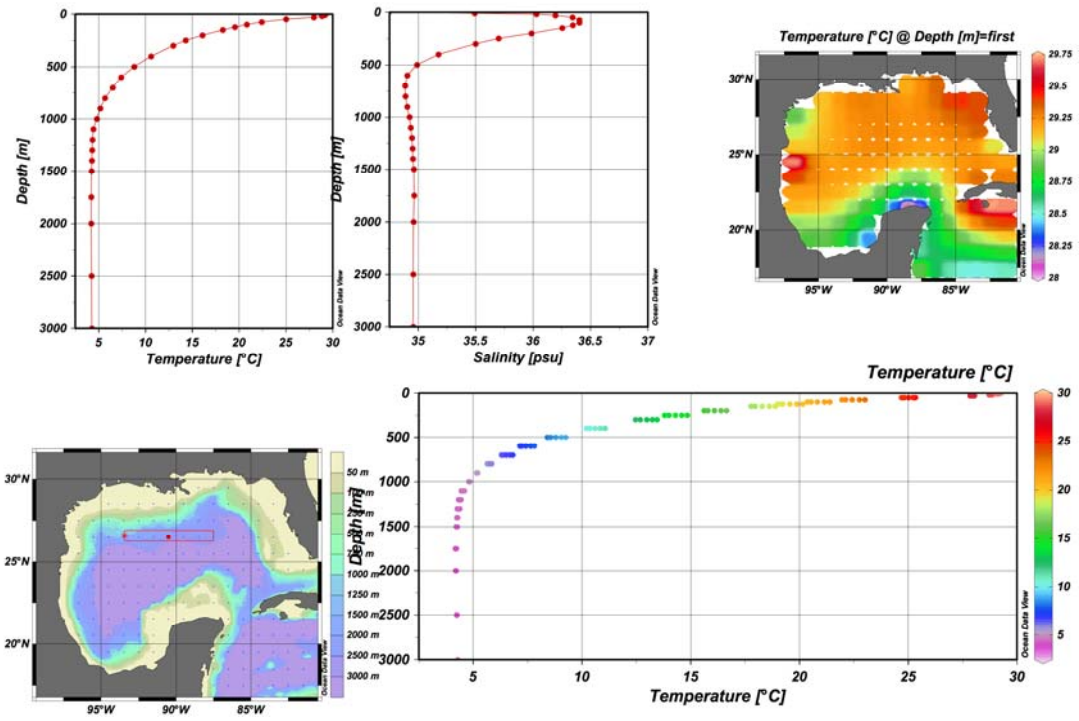

Figure 11: Clockwise from bottom left – Gulf bathymetry, average temperature profile at 90.5° W, 27.5° N, average salinity at 90.5° W, 27.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for summer (Jul-Sep).(ODV).

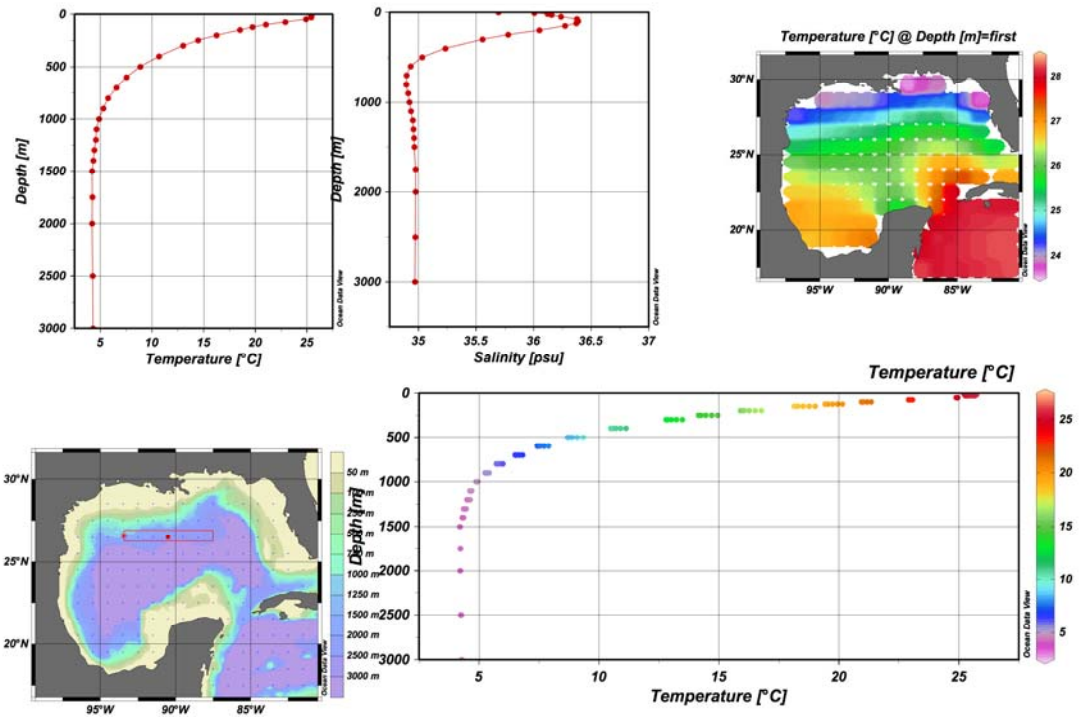

Figure 12: Clockwise from bottom left – Gulf bathymetry, average temperature profile at 90.5° W, 27.5° N, average salinity at 90.5° W, 27.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for fall (Oct-Dec). (ODV).

Table 3: Gulf of Mexico representative seasonal climatology: temperature and salinity.

	Temperature [°C]				Salinity [psu]			
Depth [m]	Winter	Spring	Summer	Fall	Spring	Spring	Summer	Fall
0	22.17	25.5	29.26	25.39	35.54	34.7	34.74	35.69
10	22.16	25.29	29.14	25.41	36.15	35.93	35.49	36.01
20	22.13	24.91	28.85	25.46	36.26	36.19	36.03	36.12
30	22.06	24.26	27.97	25.44	36.29	36.3	36.2	36.16
50	21.84	22.79	25.02	24.9	36.31	36.33	36.34	36.24
75	21.4	21.42	22.42	22.91	36.38	36.37	36.4	36.38
100	20.46	20.32	20.82	21.02	36.4	36.38	36.41	36.39
125	19.25	19.12	19.56	19.73	36.36	36.34	36.35	36.37
150	18.18	18.01	18.28	18.52	36.27	36.24	36.26	36.27
200	15.99	15.95	16.09	16.26	36.01	35.99	35.99	36.05
250	14.22	14.23	14.3	14.46	35.74	35.75	35.7	35.78
300	12.86	12.88	12.98	13.02	35.53	35.53	35.5	35.56
400	10.46	10.56	10.61	10.7	35.21	35.21	35.18	35.24
500	8.75	8.8	8.79	8.88	35.02	35.01	34.99	35.03
600	7.51	7.5	7.42	7.53	34.92	34.91	34.91	34.93
700	6.53	6.51	6.52	6.56	34.9	34.88	34.89	34.9
800	5.89	5.91	5.69	5.77	34.89	34.89	34.89	34.9
900	5.29	5.23	5.16	5.3	34.91	34.9	34.91	34.91
1000	4.86	4.88	4.8	4.88	34.93	34.92	34.92	34.92
1100	4.49	4.65	4.46	4.63	34.94	34.93	34.94	34.94
1200	4.4	4.45	4.34	4.58	34.97	34.94	34.95	34.95
1300	4.29	4.34	4.32	4.42	34.96	34.96	34.95	34.96
1400	4.22	4.29	4.28	4.34	34.96	34.96	34.95	34.96
1500	4.21	4.28	4.25	4.2	34.97	34.96	34.96	34.97
1750	4.2	4.25	4.2	4.23	34.96	34.96	34.97	34.98
2000	4.21	4.19	4.21	4.22	34.97	34.97	34.96	34.98
2500	4.24	4.22	4.25	4.26	34.97	34.97	34.96	34.97
3000	4.3	4.26	4.29	4.29	34.97	34.97	34.96	34.97

2.3 North Sea

Figure 13: North Sea area (from Wikipedia).

The North Sea is bounded by the Orkney Islands and east coasts of England and Scotland to the west and the northern and central European mainland to the east and south. In the south-west, beyond the Straits of Dover, the North Sea becomes the English Channel, connecting to the Atlantic Ocean. In the east, it connects to the Baltic Sea via the Skagerrak and Kattegat, narrow straits that separate Denmark from Norway and Sweden respectively. In the north it is bordered by the Shetland Islands, and connects with the Norwegian Sea, which lies in the very north-eastern part of the Atlantic.

The North Sea receives freshwater from a number of European continental watersheds, as well as the British Isles island watersheds. A large part of the European drainage basin empties into the North Sea including water from the Baltic Sea.

For the most part, the sea lies on the European continental shelf with a mean depth of approximately 90 metres, with the Norwegian trench, which extends parallel to the Norwegian shoreline, being up to 725 m deep. Figure 14 shows the bathymetry of the North Sea, as well as sediment thicknesses in the North Sea.

The main pattern to the flow of water in the North Sea is an anti-clockwise rotation along the edges, with significant tides near the English coast.

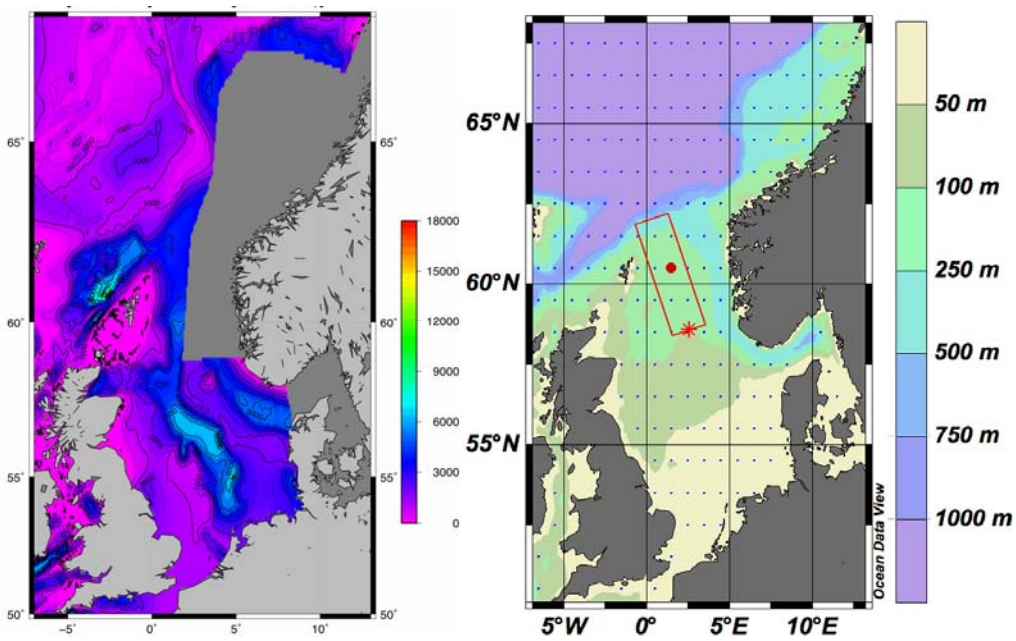

Figure 14: North Sea sediment thickness (data from [27]).and bathymetry (from ETOPO5). (ODV).

There is a great deal of information available on the geology of the North Sea, to fairly high degrees of detail, including several books on the petroleum geology of the area (e.g. [28]). Reports from the British Geological Survey on the DTI Strategic Environmental Assessment Areas are also available, providing information on the geology of the North Sea (see e.g. Figure 15, from [29]).

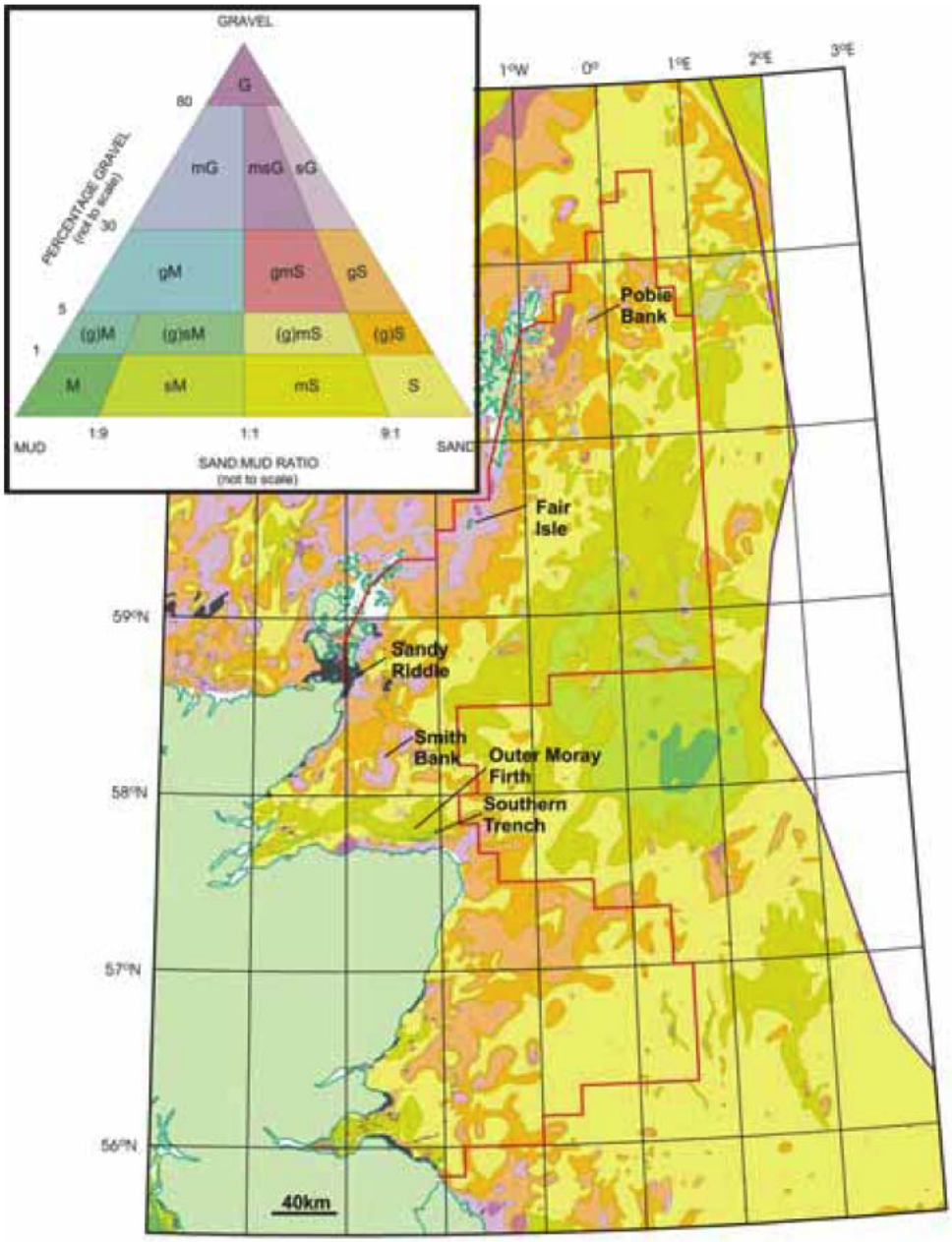

Figure 15: North Sea SEA5 seabed sediment types (from [29]).

Examining the area near 60.5° N, 1.5° E as a representative example near the suggested depth, the upper sediment is primarily sand with some silt/clay.

Representative climatological temperature and salinity information for each season in the North Sea is shown in Figures 16 through 19, and the temperature and salinity profiles at a representative point are given in Table 4.

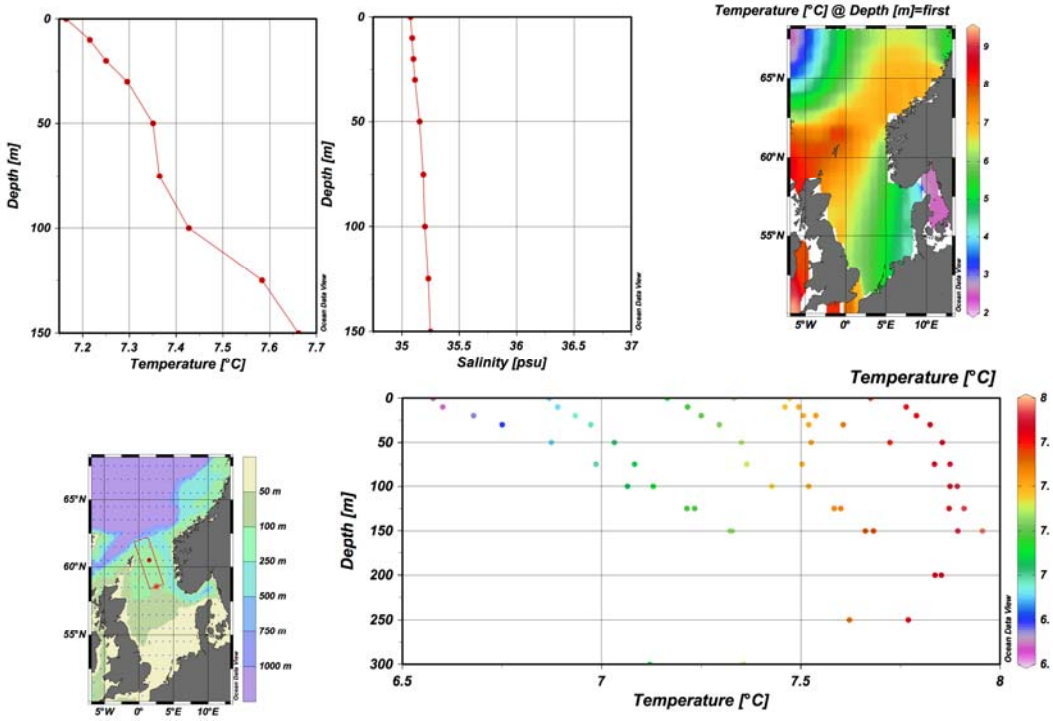

Figure 16: Clockwise from bottom left – North Sea bathymetry, average temperature profile at 1.5° E, 60.5° N, average salinity at 1.5° E, 60.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for winter (Jan-Mar). (ODV).

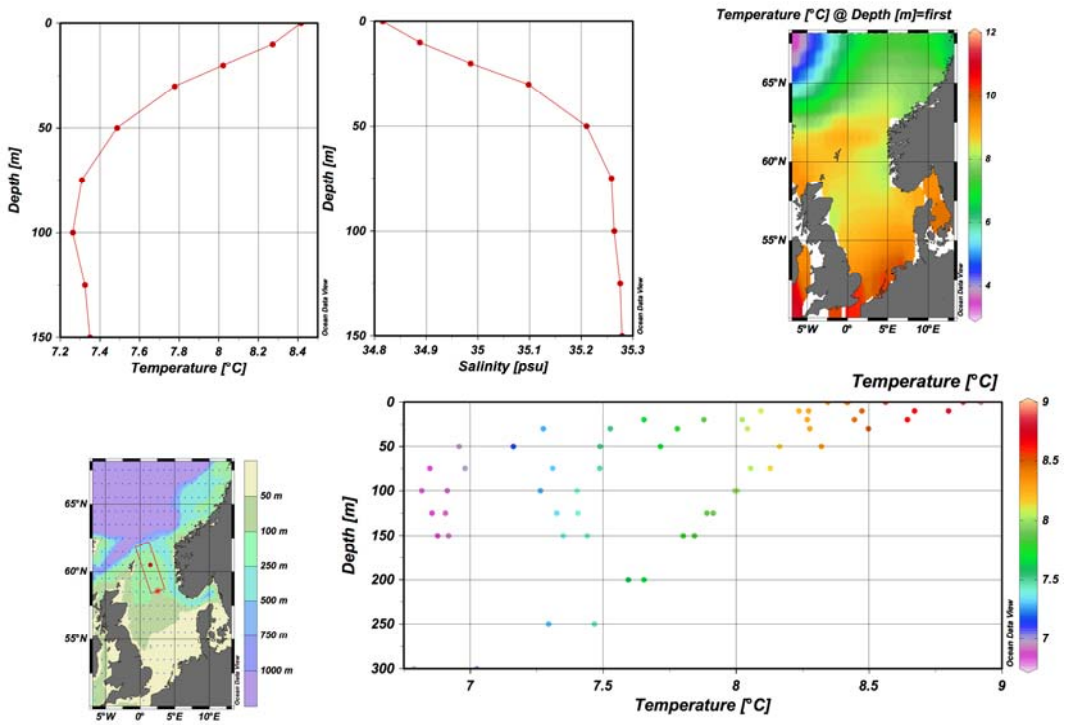

Figure 17: Clockwise from bottom left – North Sea bathymetry, average temperature profile at 1.5° E, 60.5° N, average salinity at 1.5° E, 60.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for spring (Apr-Jun). (ODV).

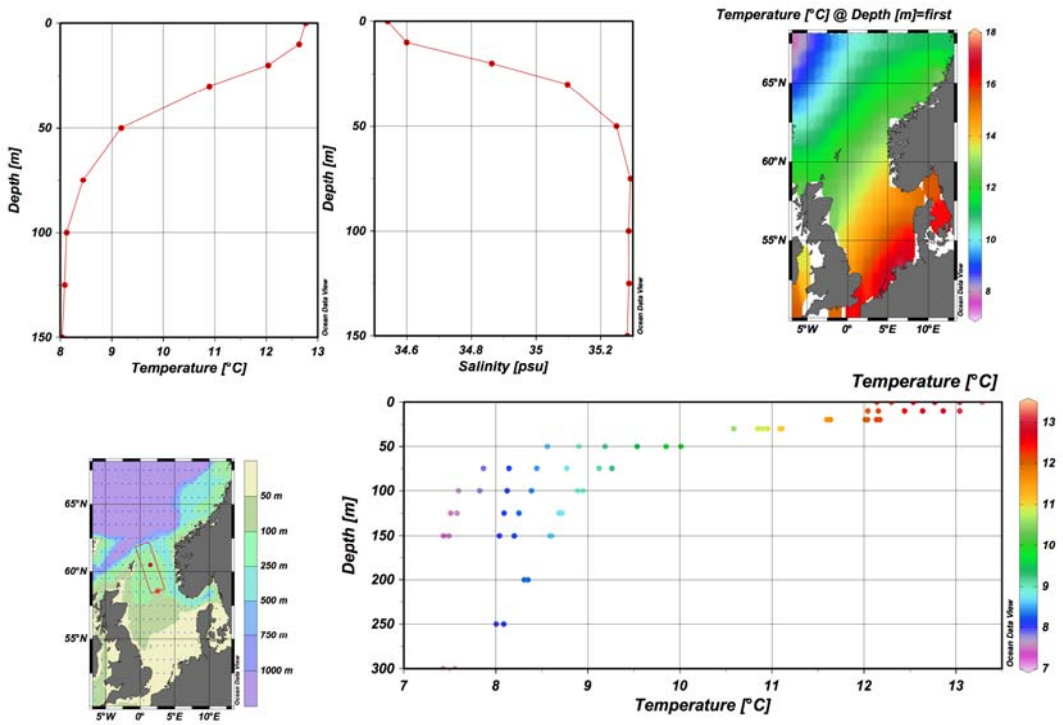

Figure 18: Clockwise from bottom left – North Sea bathymetry, average temperature profile at 1.5° E, 60.5° N, average salinity at 1.5° E, 60.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for summer (Jul-Sep).(ODV).

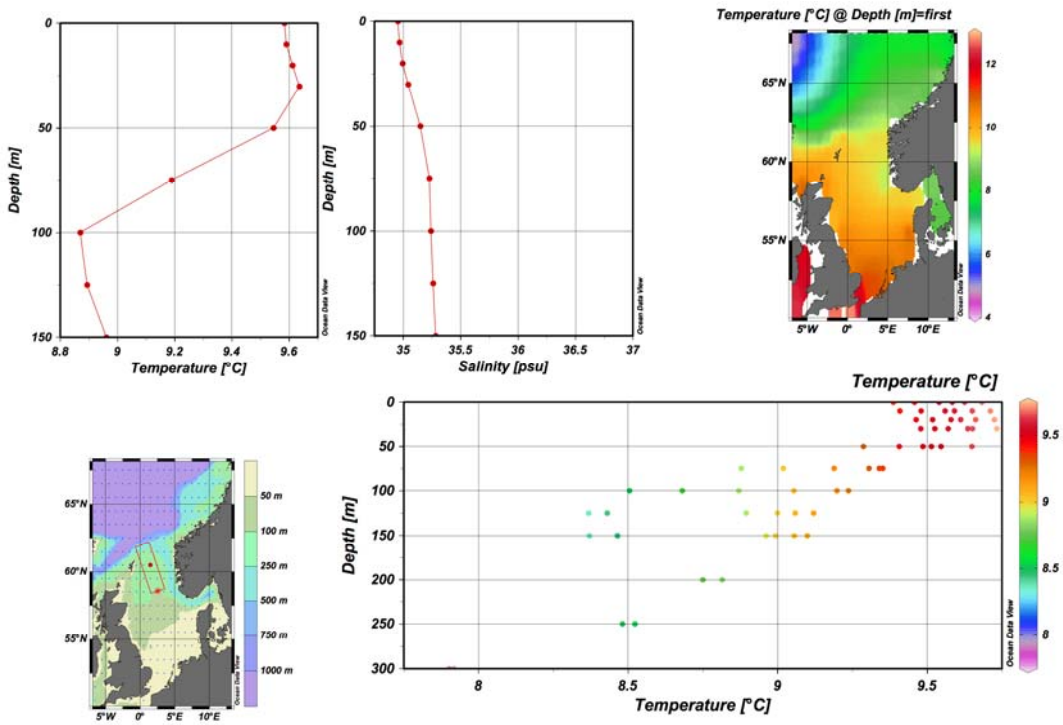

Figure 19: Clockwise from bottom left – North Sea bathymetry, average temperature profile at 1.5° E, 60.5° N, average salinity at 1.5° E, 60.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for fall (Oct-Dec). (ODV).

Table 4: North Sea representative seasonal climatology: temperature and salinity.

	Temperature [°C]				Salinity [psu]			
Depth [m]	Winter	Spring	Summer	Fall	Spring	Spring	Summer	Fall
0	7.16	8.42	12.77	9.58	35.08	34.82	34.54	34.95
10	7.22	8.27	12.64	9.59	35.09	34.89	34.6	34.97
20	7.25	8.02	12.04	9.61	35.1	34.99	34.86	35
30	7.3	7.78	10.9	9.64	35.12	35.1	35.1	35.04
50	7.35	7.49	9.19	9.55	35.16	35.21	35.25	35.15
75	7.36	7.31	8.44	9.19	35.19	35.26	35.29	35.23
100	7.43	7.26	8.12	8.87	35.2	35.26	35.29	35.24
125	7.58	7.33	8.09	8.89	35.23	35.28	35.29	35.26
150	7.66	7.35	8.04	8.96	35.25	35.28	35.28	35.28

2.4 West Coast of Africa (offshore Nigeria or Angola)

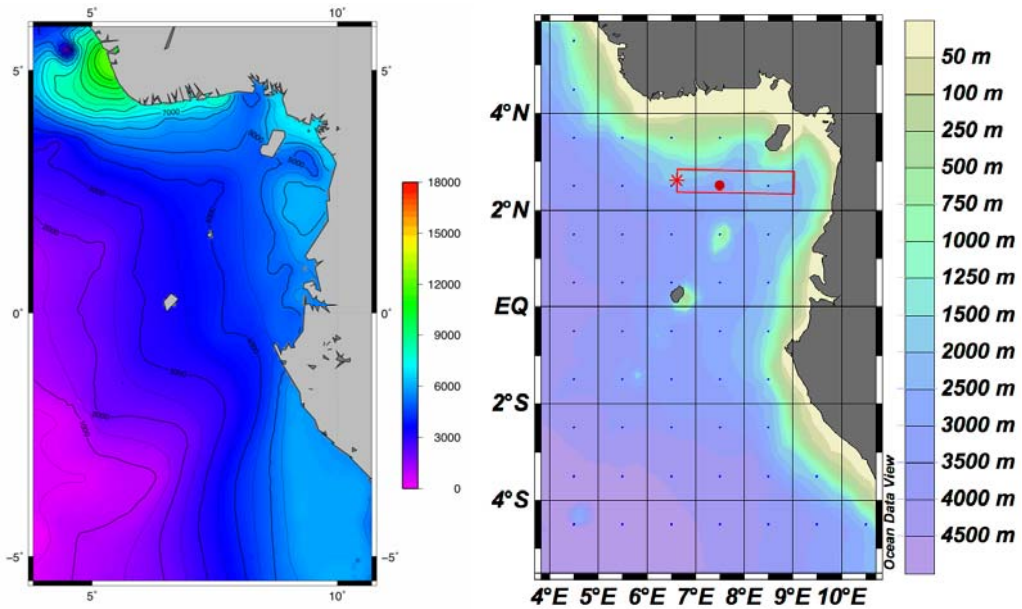

Figure 20: Offshore Nigeria sediment thickness (data from [27]) and bathymetry (from ETOPO5).

The geology of the Nigerian continental slope, particularly as regards gas hydrates present offshore, has been examined in several papers and books (e.g. [30, 31, 32]). The upper sediment on the continental slope consists mainly of silty clays, with some outcroppings of quartz sand with quantities of shells [33]. Figure 20 shows sediment thickness and bathymetry of the area off the West African coast.

Representative climatological temperature and salinity information for each season in the Atlantic off the Nigerian coast is shown in Figures 21 through 24, and the temperature and salinity profiles at a representative point are given in Table 5.

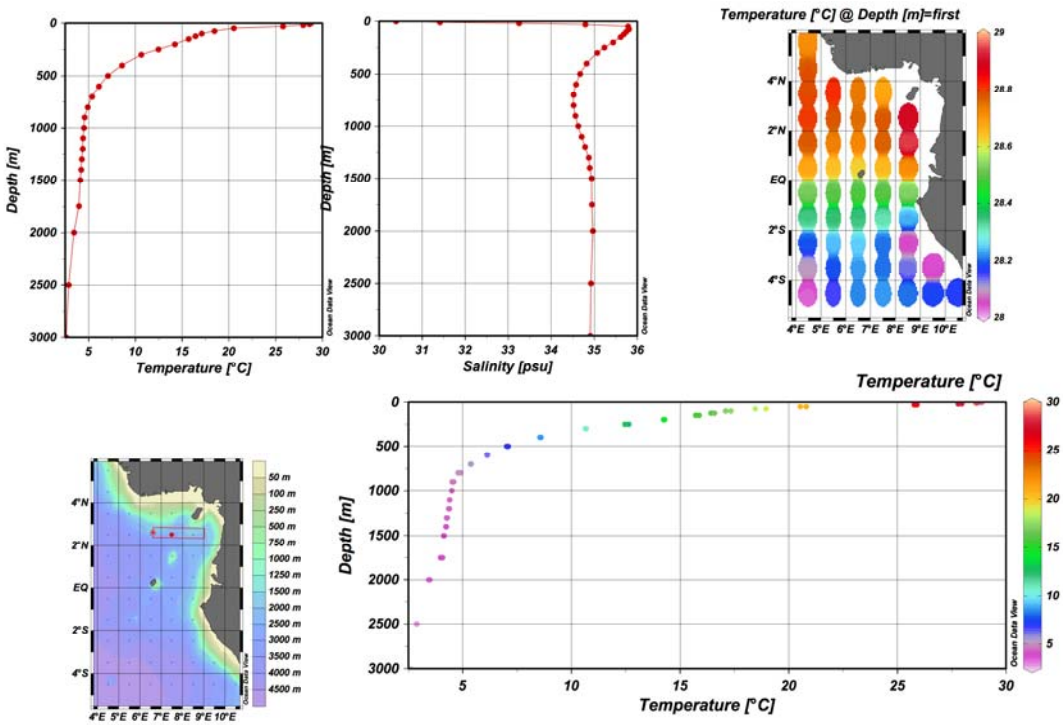

Figure 21: Clockwise from bottom left – bathymetry, average temperature profile at 7.5° E, 2.5° N, average salinity at 7.5° E, 2.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for winter (Jan-Mar). (ODV).

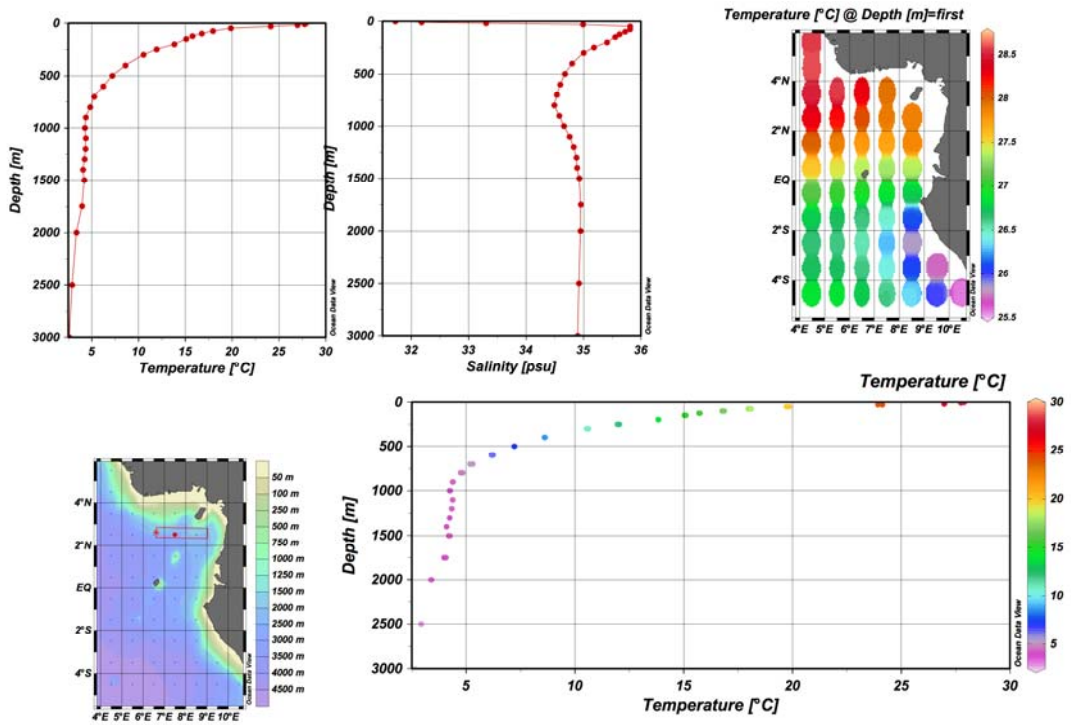

Figure 22: Clockwise from bottom left – bathymetry, average temperature profile at 7.5° E, 2.5° N, average salinity at 7.5° E, 2.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for spring (Apr-Jun). (ODV).

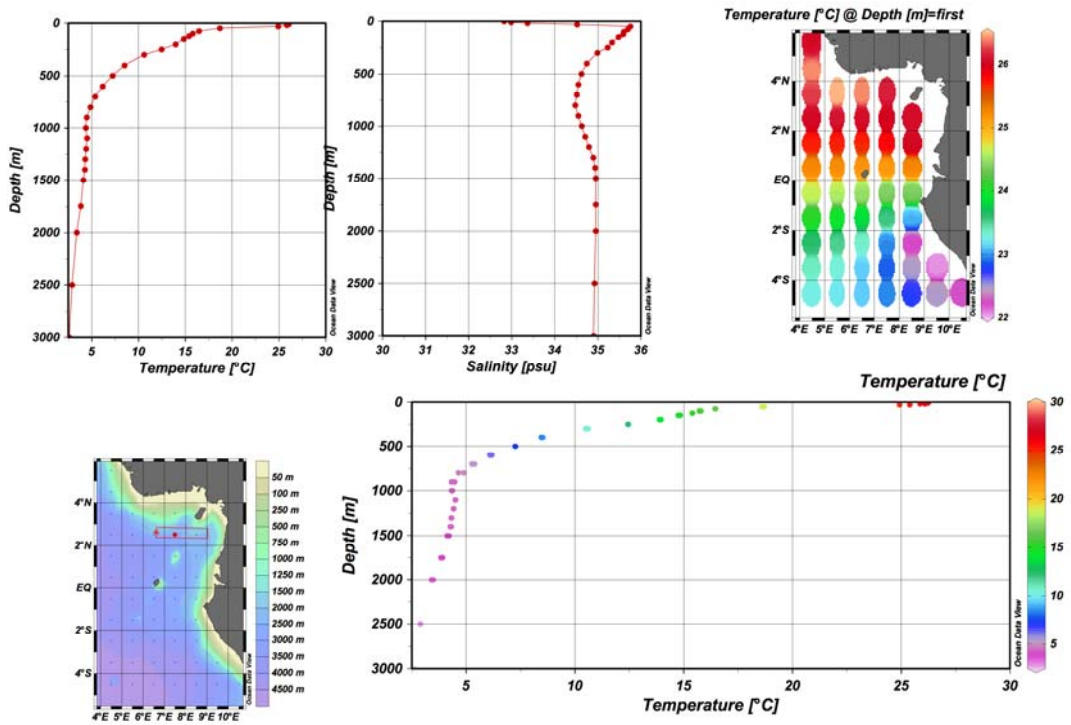

Figure 23: Clockwise from bottom left – bathymetry, average temperature profile at 7.5° E, 2.5° N, average salinity at 7.5° E, 2.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for summer (Jul-Sep).(ODV).

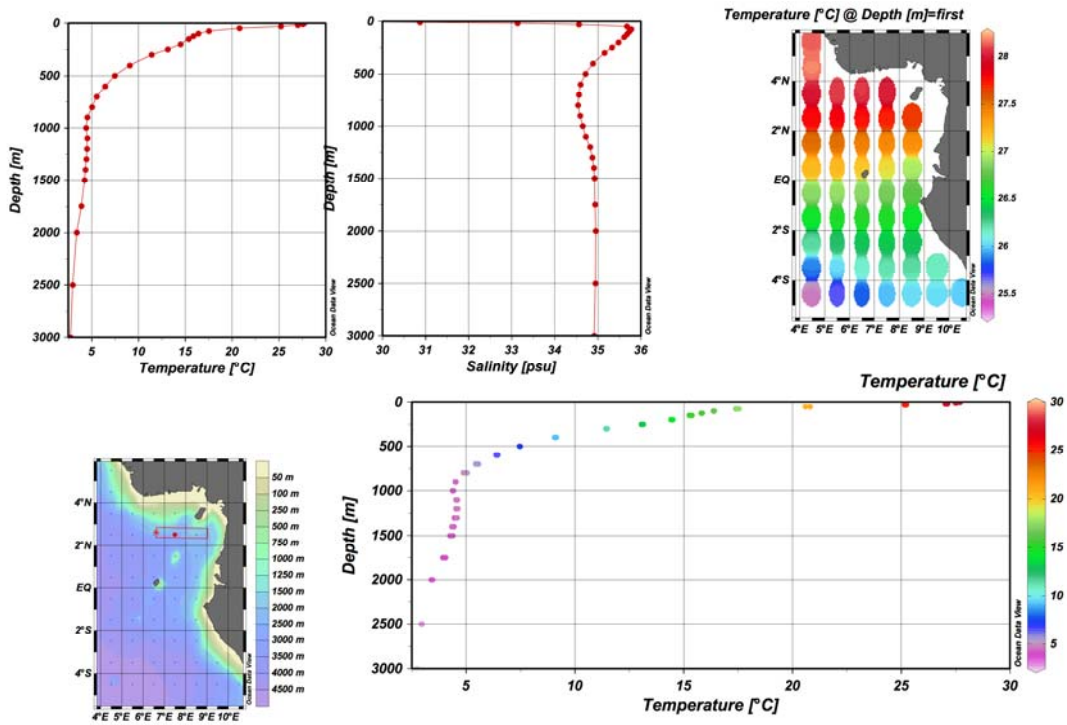

Figure 24: Clockwise from bottom left – bathymetry, average temperature profile at 7.5° E, 2.5° N, average salinity at 7.5° E, 2.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for fall (Oct-Dec). (ODV).

Table 5: West Africa coast representative seasonal climatology: temperature and salinity.

	Temperature [°C]				Salinity [psu]			
Depth [m]	Winter	Spring	Summer	Fall	Spring	Spring	Summer	Fall
0	28.77	27.9	25.98	27.71	30.39	31.73	32.83	28.14
10	28.62	27.74	26.07	27.55	31.42	32.18	32.98	30.87
20	27.95	26.99	25.87	27.02	33.25	33.31	33.37	33.14
30	25.78	24.13	24.93	25.23	34.8	34.99	34.52	34.56
50	20.54	19.85	18.7	20.81	35.78	35.81	35.76	35.68
75	18.46	17.97	16.46	17.54	35.81	35.81	35.7	35.78
100	17.1	16.76	15.79	16.41	35.75	35.73	35.6	35.73
125	16.42	15.75	15.41	15.86	35.68	35.63	35.59	35.68
150	15.72	15.1	14.85	15.37	35.61	35.55	35.49	35.61
200	14.24	13.83	13.96	14.5	35.44	35.41	35.33	35.49
250	12.47	11.95	12.46	13.14	35.23	35.18	35.23	35.33
300	10.65	10.53	10.6	11.42	35.07	35	34.99	35.16
400	8.59	8.6	8.52	9.07	34.82	34.8	34.74	34.89
500	7.09	7.22	7.25	7.48	34.67	34.68	34.62	34.72
600	6.12	6.23	6.18	6.44	34.57	34.6	34.55	34.6
700	5.39	5.3	5.39	5.55	34.52	34.54	34.51	34.56
800	4.9	4.84	4.89	5.04	34.52	34.49	34.48	34.54
900	4.58	4.4	4.47	4.53	34.56	34.58	34.55	34.59
1000	4.5	4.27	4.37	4.41	34.63	34.66	34.63	34.65
1100	4.4	4.37	4.5	4.53	34.71	34.76	34.71	34.73
1200	4.38	4.34	4.43	4.52	34.79	34.83	34.8	34.83
1300	4.28	4.24	4.32	4.46	34.87	34.88	34.9	34.88
1400	4.22	4.1	4.27	4.34	34.9	34.89	34.94	34.91
1500	4.12	4.2	4.13	4.26	34.94	34.93	34.96	34.93
1750	3.99	3.99	3.84	3.92	34.95	34.96	34.96	34.94
2000	3.44	3.38	3.41	3.4	34.97	34.95	34.95	34.95
2500	2.89	2.93	2.9	2.97	34.93	34.92	34.92	34.94
3000	2.62	2.63	2.62	2.74	34.91	34.9	34.91	34.92

2.5 Northwest Shelf, Australia

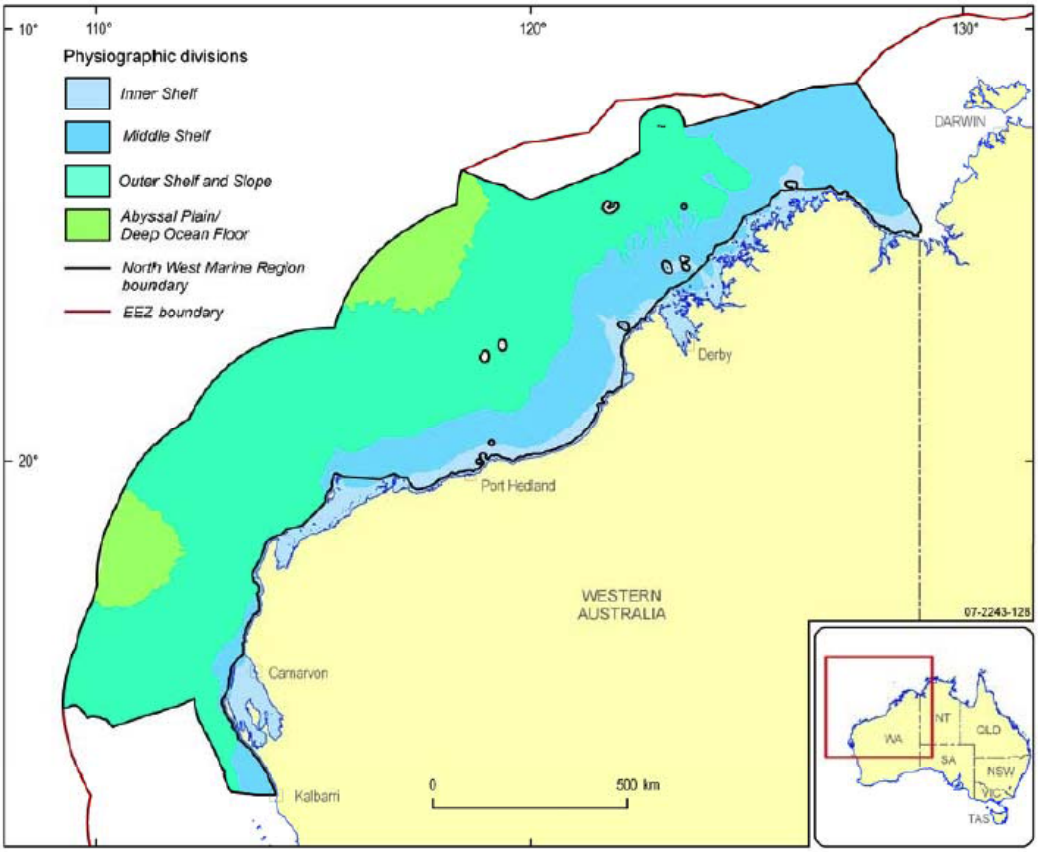

Figure 25: Physiographic divisions of Northwest shelf region (from [34]).

The physiographic divisions of the Northwest shelf region of Australia are shown in Figure 25. Given the depth selected, it is the outer shelf and slope that are the areas of interest off the Northwest coast of Australia. Here, the bottom sediments are primarily carbonate sands, with increasing proportions of mud (modern pelagic ooze and aragonitic needle, rich micrite [35]) with deepening water. Along the slope, 20-80% of the composition is mud [34]. Figures 26 and 27 illustrate the bathymetry, sediment thickness, and sediment types found in the area.

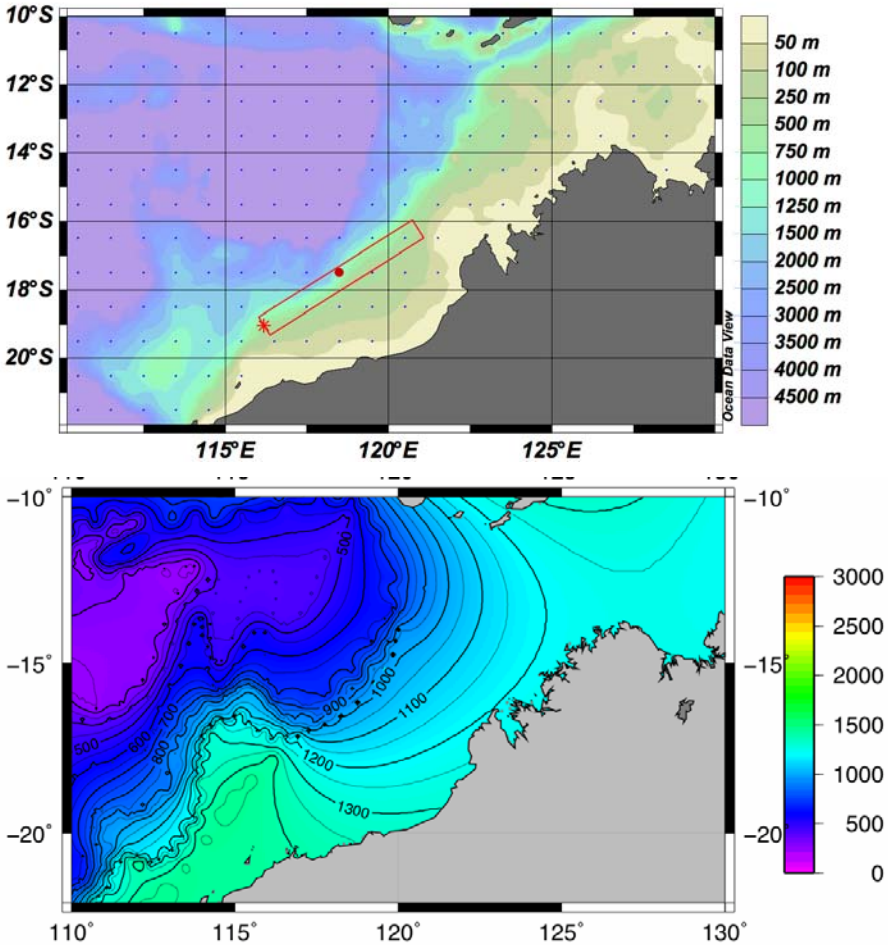

Figure 26: Northwest shelf sediment thickness (data from [27]) and bathymetry (from ETOPO5).

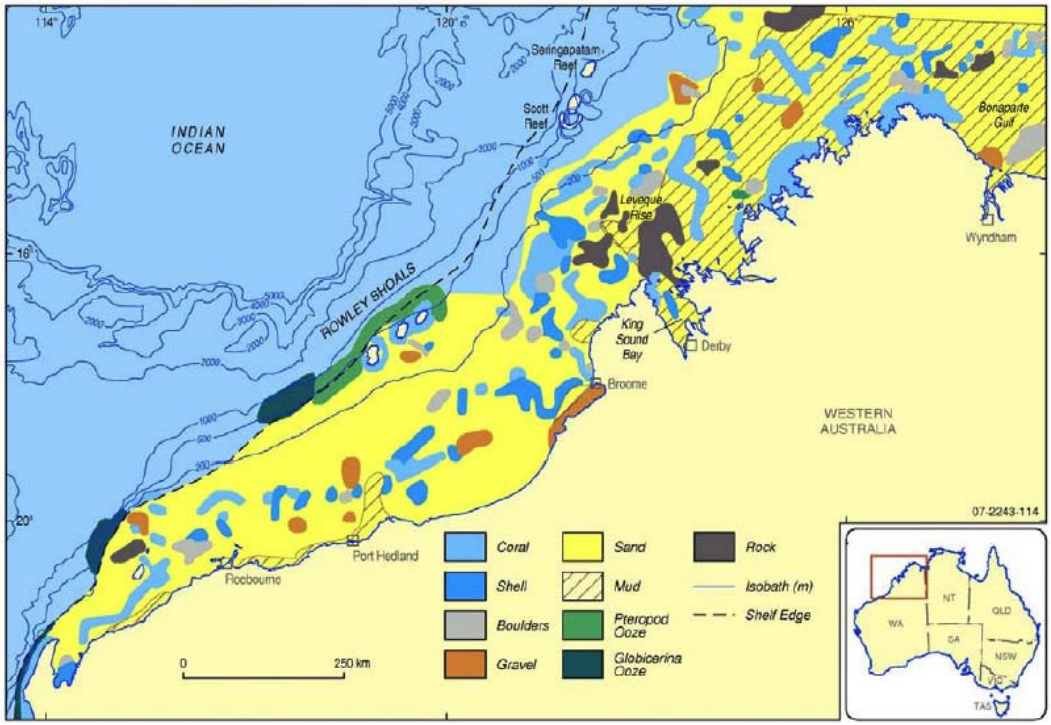

Figure 27: Sedimentary facies model of the northwest shelf [36] (from [34]).

Representative climatological temperature and salinity information for each season for the NW Australian Shelf area is shown in Figures 28 through 31, and the temperature and salinity profiles at a representative point are given in Table 6.

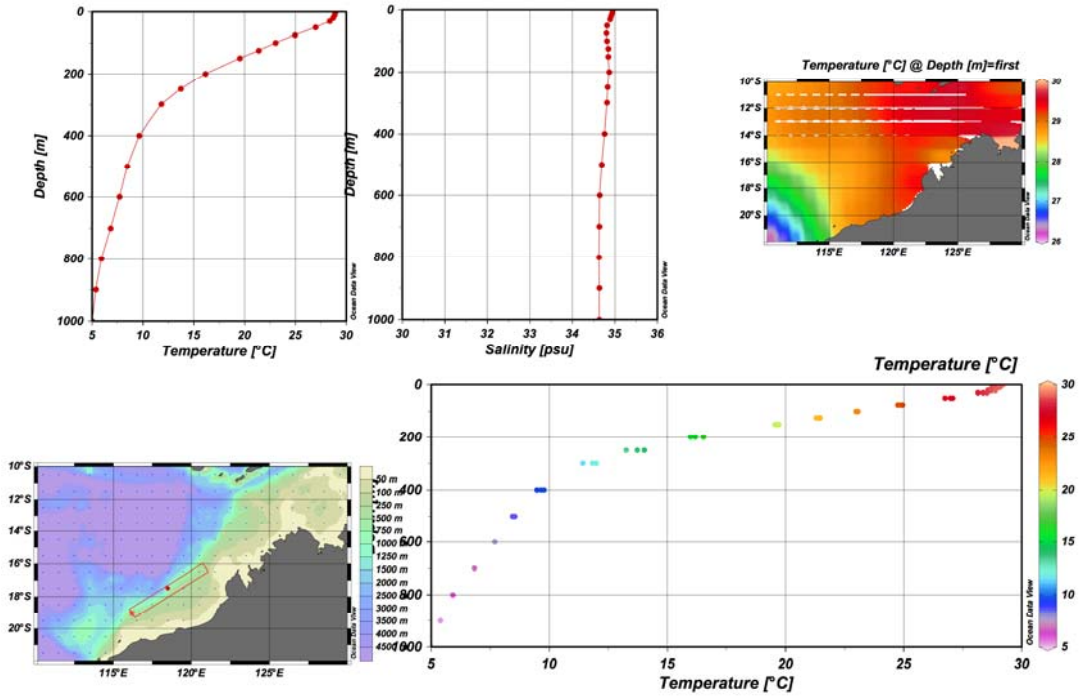

Figure 28: Clockwise from bottom left – NW Australia bathymetry, average temperature profile at 118.5° E, 17.5° S, average salinity at 118.5° E, 17.5° S, surface temperature, and temperature profiles along section (red box in bathymetry map), for winter (Jan-Mar). (ODV).

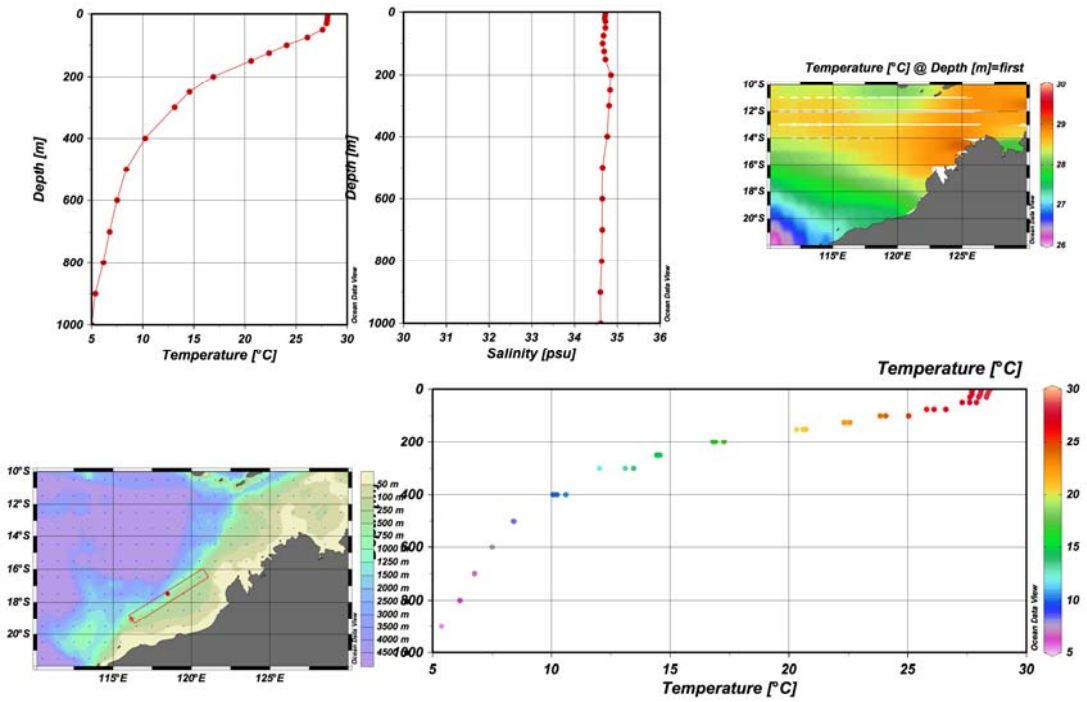

Figure 29: Clockwise from bottom left – NW Australia bathymetry, average temperature profile at 118.5° E, 17.5° S, average salinity at 118.5° E, 17.5° S, surface temperature, and temperature profiles along section (red box in bathymetry map), for spring (Apr-Jun). (ODV).

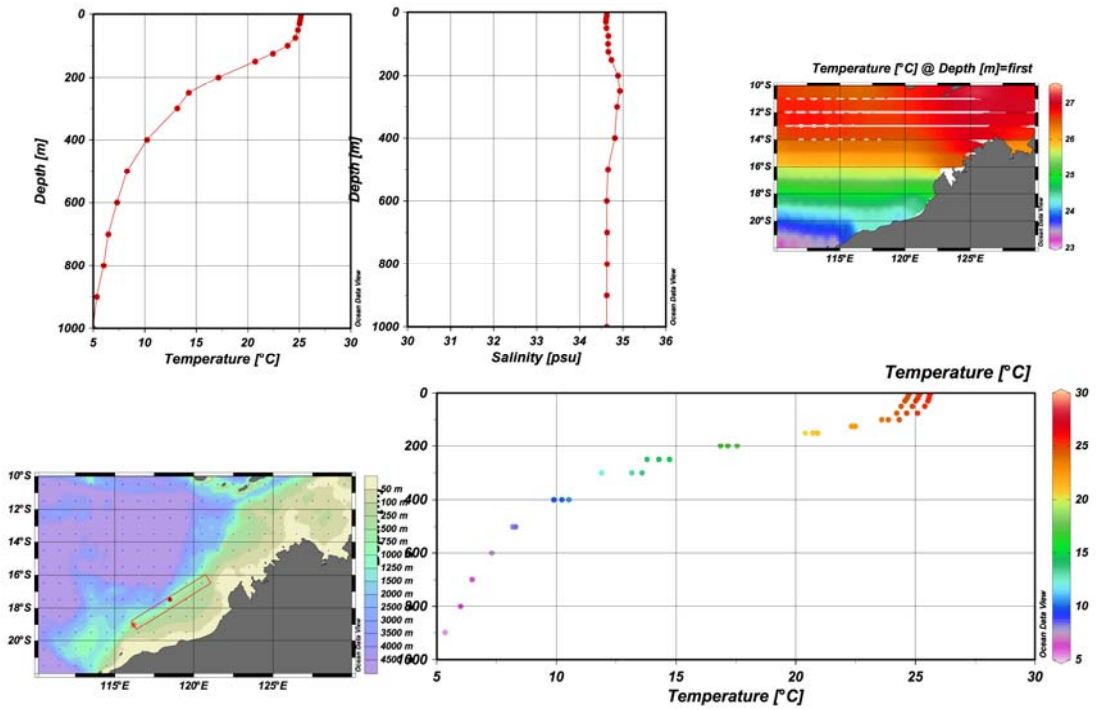

Figure 30: Clockwise from bottom left – NW Australia bathymetry, average temperature profile at 118.5° E, 17.5° S, average salinity at 118.5° E, 17.5° S, surface temperature, and temperature profiles along section (red box in bathymetry map), for summer (Jul-Sep).(ODV).

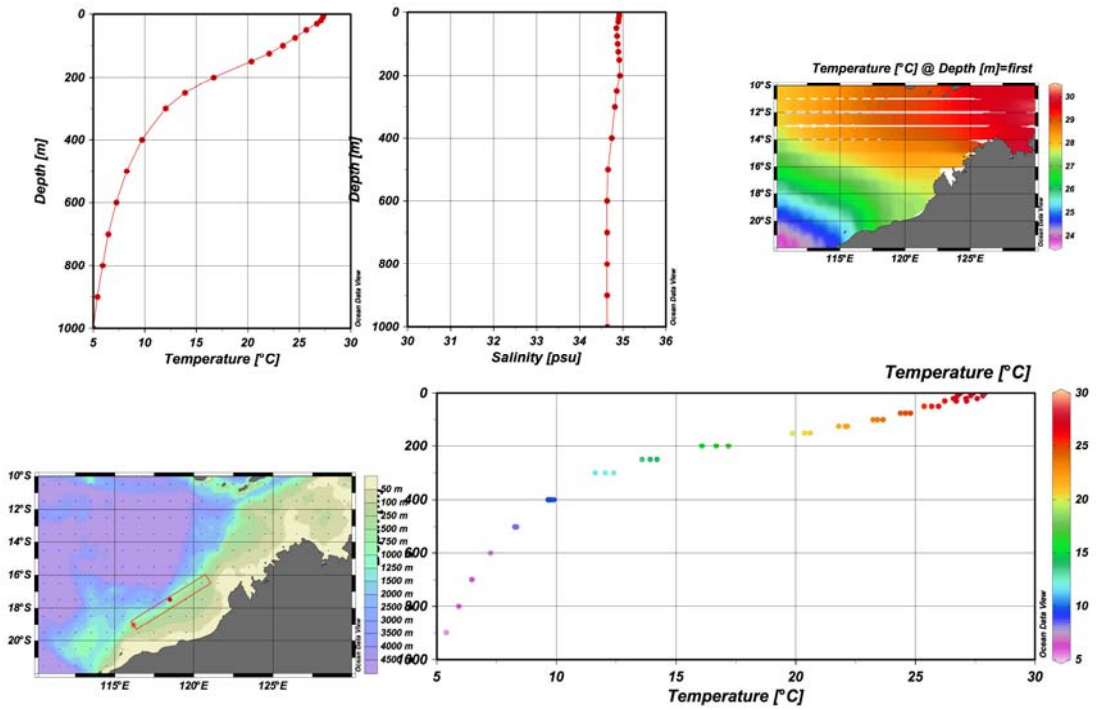

Figure 31: Clockwise from bottom left NW Australia bathymetry, average temperature profile at 118.5° E, 17.5° S, average salinity at 118.5° E, 17.5° S, surface temperature, and temperature profiles along section (red box in bathymetry map), for fall (Oct-Dec). (ODV).

Table 6: NW Australia Shelf representative seasonal climatology: temperature and salinity.

	Temperature [°C]				Salinity [psu]			
Depth [m]	Winter	Spring	Summer	Fall	Spring	Spring	Summer	Fall
0	28.95	28.11	25.21	27.41	34.94	34.73	34.63	34.91
10	28.85	28.07	25.15	27.31	34.94	34.71	34.63	34.92
20	28.71	28.05	25.1	27.11	34.91	34.7	34.61	34.9
30	28.37	27.98	25.01	26.71	34.89	34.72	34.61	34.89
50	26.99	27.6	24.87	25.69	34.81	34.73	34.62	34.85
75	24.96	26.11	24.64	24.59	34.8	34.68	34.67	34.87
100	23.06	24.08	23.88	23.41	34.82	34.66	34.66	34.88
125	21.37	22.36	22.43	22.08	34.84	34.69	34.67	34.9
150	19.56	20.59	20.72	20.36	34.84	34.73	34.74	34.92
200	16.17	16.9	17.16	16.69	34.86	34.85	34.89	34.93
250	13.72	14.57	14.28	13.91	34.83	34.83	34.93	34.86
300	11.83	13.11	13.15	12.04	34.82	34.81	34.87	34.82
400	9.64	10.24	10.23	9.75	34.76	34.77	34.81	34.74
500	8.45	8.4	8.29	8.27	34.69	34.66	34.66	34.66
600	7.7	7.5	7.3	7.24	34.64	34.65	34.63	34.63
700	6.82	6.76	6.48	6.47	34.63	34.65	34.64	34.63
800	5.92	6.16	6	5.91	34.63	34.63	34.63	34.64
900	5.38	5.37	5.34	5.4	34.63	34.61	34.63	34.64
1000	5	5.03	4.99	5	34.64	34.61	34.63	34.64

2.6 Persian Gulf

The geology of the Persian Gulf has been well-studied in relation to the production of petroleum. The bathymetry of the Gulf is pictured in Figure 32.

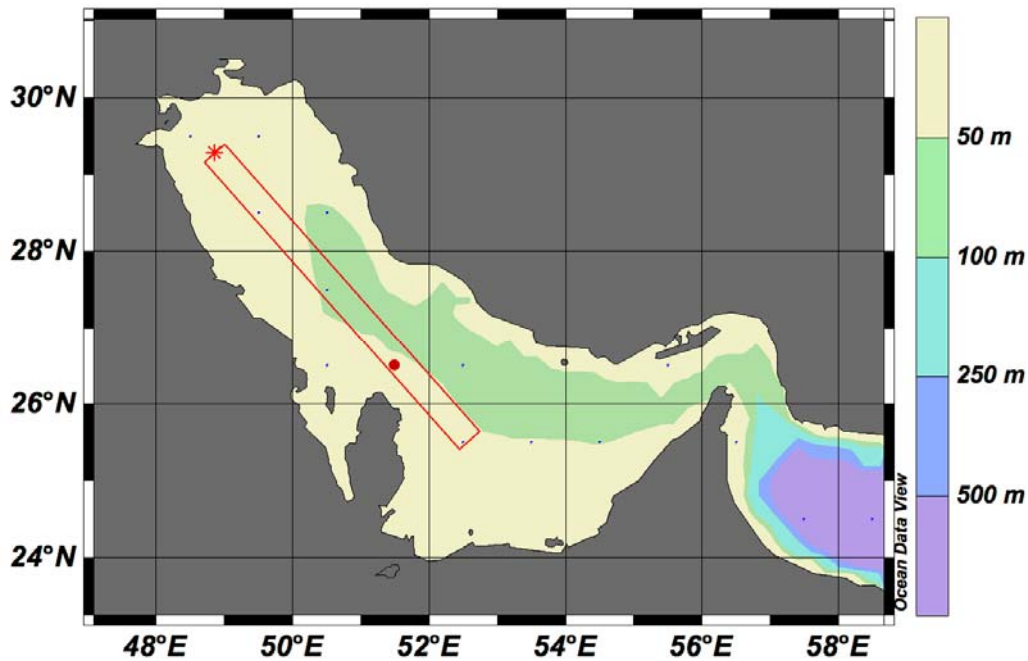

Figure 32: Persian Gulf bathymetry (from ETOPO5).

The Gulf is typically no more than 100 m deep, with a number of islands that are primarily salt domes or coral or shell debris. The surface sediments in the deeper parts of the Persian Gulf lying near the coast of Iran are mostly carbonate-rich fine muds, while the shallower areas in the south-west are skeletal sands and carbonate muds. The sea floor has also been hardened in many areas by calcium carbonate (limestone) deposition, and much of the underlying sediment is also limestone.

The Gulf is very warm and salty, although less so near the mouths of the Tigris/Euphrates. A reasonably representative spot was chosen at 51.5° E, 26.5° N. Representative climatological temperature and salinity information for each season in the Persian Gulf is shown in Figures 33 through 36, and the temperature and salinity profiles at a representative point are given in Table 7.

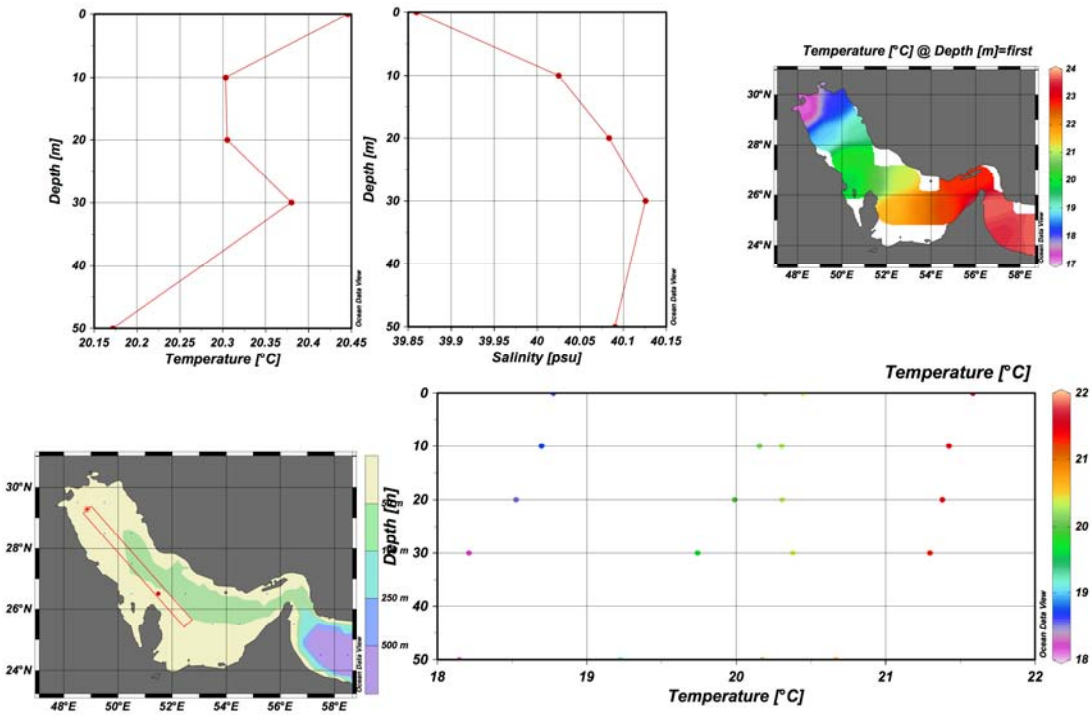

Figure 33: Clockwise from bottom left – Persian Gulf bathymetry, average temperature profile at 51.5° E, 26.5° N, average salinity at 51.5° E, 26.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for winter (Jan-Mar). (ODV).

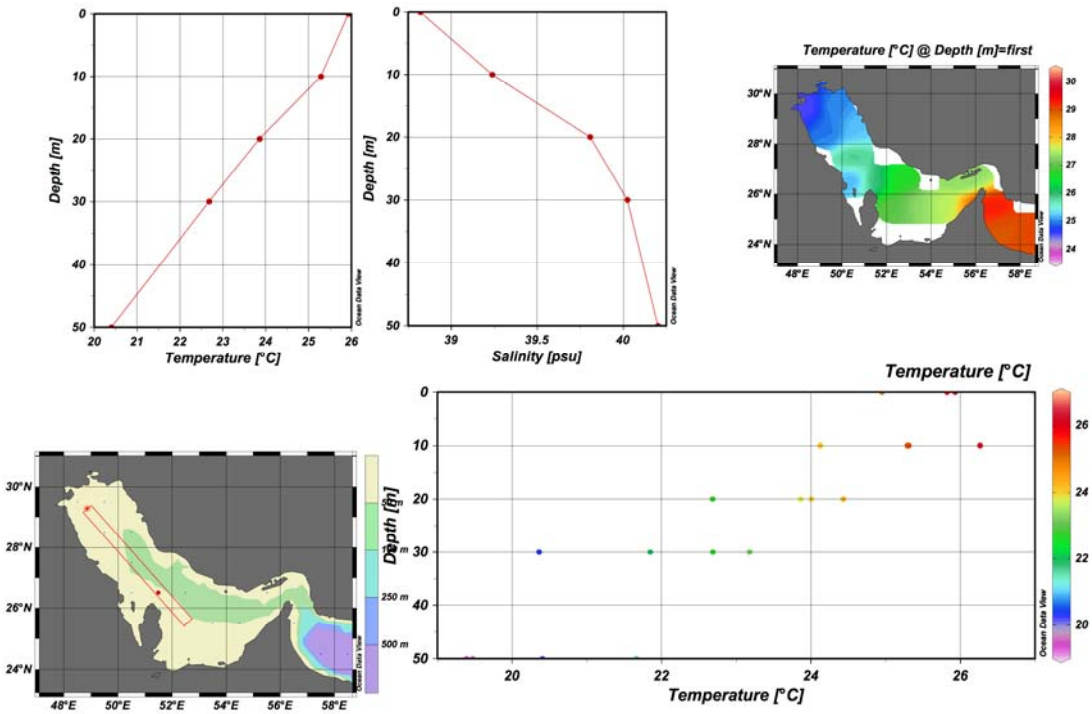

Figure 34: Clockwise from bottom left – Persian Gulf bathymetry, average temperature profile at 51.5° E, 26.5° N, average salinity at 51.5° E, 26.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for spring (Apr-Jun). (ODV).

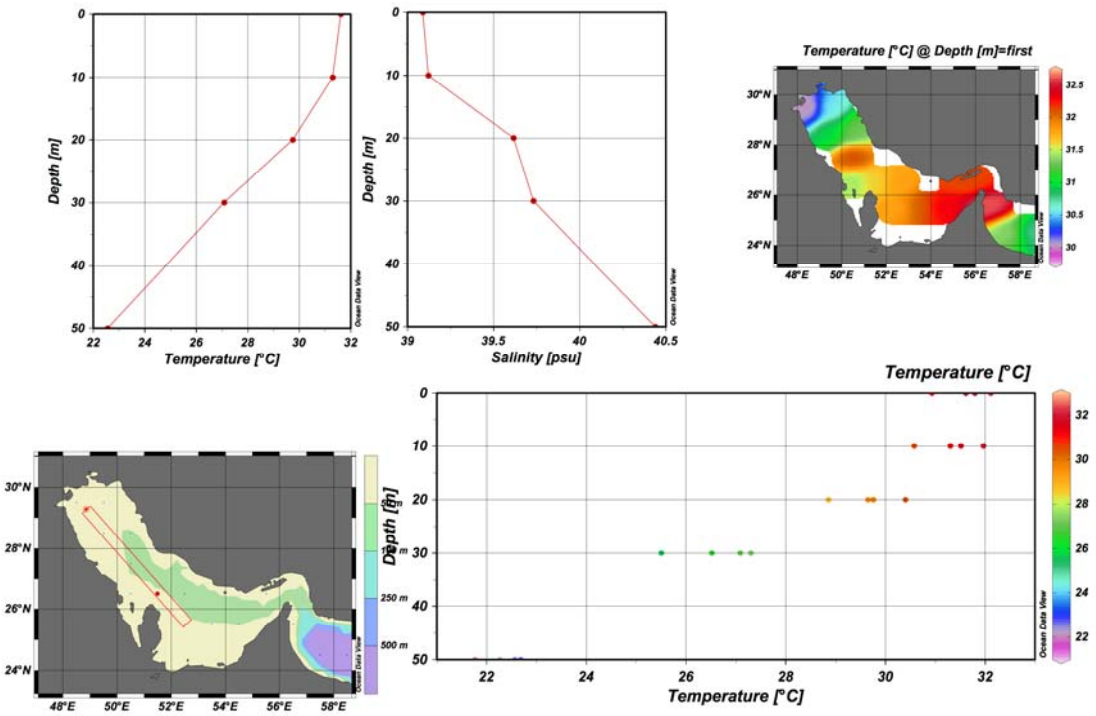

Figure 35: Clockwise from bottom left – Persian Gulf bathymetry, average temperature profile at 51.5° E, 26.5° N, average salinity at 51.5° E, 26.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for summer (Jul-Sep).(ODV).

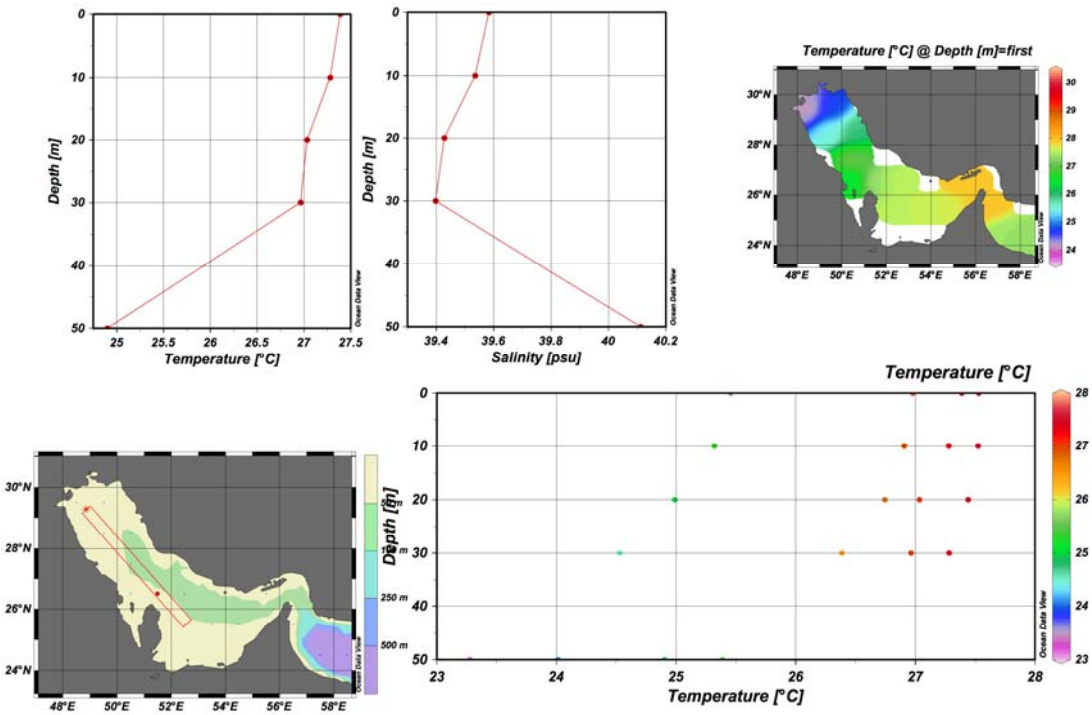

Figure 36: Clockwise from bottom left – Persian Gulf bathymetry, average temperature profile at 51.5° E, 26.5° N, average salinity at 51.5° E, 26.5° N, surface temperature, and temperature profiles along section (red box in bathymetry map), for fall (Oct-Dec). (ODV).

Table 7: Persian Gulf representative seasonal climatology: temperature and salinity.

	Temperature [°C]				Salinity [psu]			
Depth [m]	Winter	Spring	Summer	Fall	Spring	Spring	Summer	Fall
0	20.45	25.93	31.61	27.39	39.86	38.82	39.09	39.58
10	20.3	25.29	31.3	27.28	40.03	39.24	39.12	39.54
20	20.31	23.86	29.76	27.03	40.08	39.81	39.62	39.43
30	20.38	22.69	27.09	26.97	40.13	40.02	39.73	39.4
50	20.17	20.41	22.57	24.9	40.09	40.2	40.44	40.11

3 Marine Mammal within E&P Environments

To develop an understanding of the types of marine mammals in the six environments above, a list of 86 species of marine mammals and their habitat was cross referenced with the six locations.

3.1 Introduction

A list of 86 marine mammals was compiled from information on the International Union for Conservation of Nature (IUCN) website. The habitats of these marine mammals (as described on the IUCN website) were cross referenced with the six environments identified in the previous section of this Volume to provide a summary of the marine mammals present in the areas.

Table 8 below contains the list of marine mammals, including their size, diving behaviour and IUCN status. The last six columns of the table are the six environments represented by S1 – S6 (see description in previous section, Table 1). A solid dot in the columns S1 through S6 indicates the presence of a particular mammal in that environment.

3.2 Background on the IUCN

The population health (threatened, endangered, etc.) of a species is monitored and categorized by the International Union for Conservation of Nature (IUCN)[37].

The IUCN (International Union for Conservation of Nature) serves as the largest global environmental network. Its membership includes more than 1,000 government and non-government organizations (NGO). It supports collaboration among interested parties in research, development, and implementation of policy, laws, and best practices. The IUCN Redlist is recognized as a global authoritative list of designated species.

The IUCN designates species within nine categories. Designations for the IUCN Redlist are presented in reference [38]:

> *EXTINCT (EX)*
> *A taxon is Extinct when there is no reasonable doubt that the last individual has died. A taxon is presumed Extinct when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.*
>
> *EXTINCT IN THE WILD (EW)*
> *A taxon is Extinct in the Wild when it is known only to survive in cultivation, in captivity or as a naturalized population (or populations) well outside the past range. A taxon is presumed Extinct in the Wild when exhaustive surveys in known and/or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range have failed to record an individual. Surveys should be over a time frame appropriate to the taxon's life cycle and life form.*

CRITICALLY ENDANGERED (CR)
A taxon is Critically Endangered when the best available evidence indicates that it meets any of the criteria A to E for Critically Endangered (see Section V), and it is therefore considered to be facing an extremely high risk of extinction in the wild.

ENDANGERED (EN)
A taxon is Endangered when the best available evidence indicates that it meets any of the criteria A to E for Endangered (see Section V), and it is therefore considered to be facing a very high risk of extinction in the wild.

VULNERABLE (VU)
A taxon is Vulnerable when the best available evidence indicates that it meets any of the criteria A to E for Vulnerable (see Section V), and it is therefore considered to be facing a high risk of extinction in the wild.

NEAR THREATENED (NT)
A taxon is Near Threatened when it has been evaluated against the criteria but does not qualify for Critically Endangered, Endangered or Vulnerable now, but is close to qualifying for or is likely to qualify for a threatened category in the near future.

LEAST CONCERN (LC)
A taxon is Least Concern when it has been evaluated against the criteria and does not qualify for Critically Endangered, Endangered, Vulnerable or Near Threatened. Widespread and abundant taxa are included in this category.

DATA DEFICIENT (DD)
A taxon is Data Deficient when there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on its distribution and/or population status. A taxon in this category may be well studied, and its biology well known, but appropriate data on abundance and/or distribution are lacking. Data Deficient is therefore not a category of threat. Listing of taxa in this category indicates that more information is required and acknowledges the possibility that future research will show that threatened classification is appropriate. It is important to make positive use of whatever data are available. In many cases great care should be exercised in choosing between DD and a threatened status. If the range of a taxon is suspected to be relatively circumscribed, and a considerable period of time has elapsed since the last record of the taxon, threatened status may well be justified.

NOT EVALUATED (NE)
A taxon is Not Evaluated when it is has not yet been evaluated against the criteria.

3.3 Marine Mammal Species

Table 8: Suborder Mysticeti (The Baleen Whales)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status[1]	S1	S2	S3	S4	S5	S6
Balaenidae		**Right whales**									
	Eubalaena glacialis	▪North Atlantic right whale ▪Black right whale ▪Northern right whale ▪Right whale	14-18	Shallow	EN			●			
	Eubalaena australis	▪Southern right whale ▪Chile-Peru right whale	11-17	Shallow	LC (CR)						
	Eubalaena japonica	▪North Pacific right whale ▪Northeast Pacific right whale	14-18	Shallow	EN (CR)						
	Balaena mysticetus	▪Bowhead whale ▪Bowhead ▪Greenland right whale	12-20	Shallow	LC (LR, EN, CR)	●					
Neobalaenidae		**Pygmy right whale**									
	Caperea marginata	▪Pygmy right whale	4-6.5	Shallow	DD						

[1] IUCN Designations described in Section 3.2: EX: Extinct, EW: Extinct in the Wild, CR: Critically Endangered, EN: Endangered, VU: Vulnerable, NT: Near Threatened, LC: LR: Lower risk, Least Concern, DD: Data Deficient, NE: Not Evaluated. Designations in parenthesis relate to specific sub-populations.

Table 9: Suborder Mysticeti (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
Eschrichtiidae		**Gray whale**									
	Eschrichtius robustus	▪Gray whale ▪Devil fish ▪Gray Back ▪Grey whale ▪Hard Head ▪Mussel Digger ▪Rip Sack	11-15	Shallow	LC (CR)						
Balaenopteridae		**Rorquals**									
	Megaptera novaengliae	▪Humpback whale ▪Humpbacked whale	11-19	Shallow	LC (EN)	●	●	●	●	●	●
	Balaenoptera acutorostrata	▪Minke whale ▪Common minke whale ▪Dwarf minke whale ▪Lesser rorqual ▪Little piked whale	6.5-11	Shallow	LC	●[2]	●	●	●	●	●
	Balaenoptera bonarensis	▪Antarctic minke whale	8.5-9	Shallow	DD				●[3]	●	

[2] IUCN shows some overlap with Minke whale habitat and S1.
[3] IUCN shows the Antarctic Minke whale habitat ending slightly south of S4.

Table 10: Suborder Mysticeti (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Balaenoptera brydei *Balaenoptera edeni*	▪Bryde's whale ▪Eden's whale complex ▪Common Bryde's whale ▪Pygmy Bryde's whale ▪Tropical whale	12-15.5	Shallow	DD	●			●	●	●
	Balaenoptera omurai	▪Omura's whale	[4]		DD					●[5]	
	Balaenoptera borealis	▪Sei whale ▪Coalfish whale ▪Pollack whale ▪Rudophi's rorqual	12.5-21	Shallow	EN	●[6]	●	●	●	●	●
	Balaenoptera physalis	▪Fin whale ▪Common Rorqual ▪Fin-backed whale ▪Finback ▪Finner ▪Herring whale ▪Razorback	18-27	Shallow	EN	●	●	●	●	●	●
	Balaenoptera musculus	▪Blue whale ▪Pygmy Blue whale ▪Sibbald's rorqual ▪Sulphur-bottom whale	20-34	Shallow	EN (DD, CR, VU, LR)	●	●	●	●	●	●

[4] Balaenoptera omurai is a newly discovered species (2003) with little known of its size.
[5] IUCN shows the Omura's whale habitat ending slightly north of S5.
[6] IUCN shows some overlap with Sei whale habitat and S1.

Table 11: Suborder Odontocete (Toothed whales))

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
Physeteridae		**Sperm whale**									
	Physeter macrocephalus	▪Sperm whale ▪Cachelot ▪Pot whale ▪Spermacet whale	11-20	Deep	VU	●	●	●	●	●	●
Kogiidae		**Pygmy sperm whales**									
	Kogia breviceps	▪Pygmy sperm whale	2.6-3.4	Deep	DD		●	●[7]	●	●	●
	Kogia simian	▪Dwarf sperm whale	2.2-2.7	Deep	DD		●		●	●	●
Ziphiidae		**Beaked whales**									
	Ziphius cavirostris	▪Cuvier's beaked whale	5.1-6.9	Deep	LC		●	●	●	●	●
	Berardius arnuxii	▪Arnoux's beaked whale ▪Southern four-toothed whale	10-12	Deep	DD						
	Berardius bairdii	▪Baird's beaked whale ▪Giant Bottle-nosed whale ▪North pacific bottlenose whale ▪Northern four-toothed whale	9-13	Deep	DD						

[7] IUCN shows some overlap with Pygmy Sperm whale habitat and S3.

Table 12: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Indopacetus pacificus	▪Indo-pacific beaked whale ▪Longman's beaked whale ▪Tropical bottlenose whale	6-8	Deep	DD					●	●
	Hyperoodon ampullatus	▪North atlantic bottlenose whale ▪Bottlehead ▪Northern bottlenose whale	7-10	Deep	DD			●			
	Hyperoodon planifrons	▪Southern bottlenose whale ▪Flatheaded bottlenose whale	8-10	Deep	LC						
	Mesoplodon europaeus	▪Gervais' beaked whale ▪Gulf Stream beaked whale	4.5-5.2	Deep	DD		●		●		
	Mesoplodon bidens	▪North sea beaked whale ▪Sowerby's beaked whale ▪North atlantic beaked whale	5-5.5	Deep	DD			●			
	Mesoplodon grayi	▪Gray's beaked whale ▪Southern beaked whale	5.3-5.7	Deep	DD						
	Mesoplodon hectori	▪Hector's beaked whale ▪Skew-beaked whale	<4.2	Deep	DD						
	Mesoplodon peruvianus	▪Pygmy beaked whale ▪Lesser beaked whale ▪Peruvian beaked whale	~ 4.5	Deep	DD						
	Mesoplodon bowdoini	▪Andrew's beaked whale ▪Andrews' beaked whale ▪Splaytooth beaked whale	4.5-4.9	Deep	DD						

Table 13: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Mesoplodon carlhubbsi	▪Hubbs' beaked whale ▪Arch-beaked whale ▪Hubbs's beaked whale	< 5.4	Deep	DD						
	Mesoplodon stejnegeri	▪Stejneger's beaked whale ▪Bering Sea beaked whale ▪Saber-toothed whale	2.1-2.3	Deep	DD						
	Mesoplodon layardii	▪Layard's beaked whale ▪Strap-toothed whale	5.5-6	Deep	DD						
	Mesoplodon mirus	▪True's beaked whale	< 5.3	Deep	DD			●			
	Mesoplodon traversii *Mesoplodon bahamondi*	▪Spade-toothed whale ▪Bahamondi's beaked whale ▪Traver's beaked whale ▪Bahamonde's beaked whale	5-5.5	Deep	DD						
	Mesoplodon perrini	▪Perrin's beaked whale	3.9-4.4	Deep	DD						
	Mesoplodon densirostris	▪Blainville's beaked whale	4-6	Deep	DD		●		●	●	
	Tasmacetus shepherdi	▪Shepherd's beaked whale	7	Deep	DD						
	Mesoplodon ginkgodens	▪Ginko-toothed whale	<4.9	Deep	DD						

Table 14: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
Platanistidae		**Indian river-dolphin**									
	Platanista gangetica	▪Indian river-dolphin ▪South asian river dolphin ▪Blind river dolphin ▪Ganges dolphin ▪Ganges river dolphin ▪Ganges susu ▪Indus river dolphin	2-2.6	Shallow	EN						
Iniidae		**Amazon river-dolphin**									
	Inia geoffrensis	▪Boto ▪Amazon river dolphin ▪Boutu ▪Pink river dolphin	1.5-2.7	Shallow	DD						
Lipotida*e*		▪Chinese river-dolphin	2.3-2.5	Shallow	○						
	Lipotes vexillifer	▪Changjiang dolphin ▪Chinese lake dolphin ▪White Flag dolphin ▪Whitefin dolphin ▪Yangtze river dolphin, ▪Baiji	2-2.4	Shallow	CR, Possibly EX						

Table 15: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
Pontoporiidae		**La Plata dolphin**									
	Pontoporia blainvillei	▪Franciscana ▪La Plata river dolphin ▪Rio Grand do Sul/ Uruguay franciscana	1.6-1.8	Shallow	VU						
Monodontidae		**Beluga and narwhal**									
	Monodon monocerus	▪Narwhal ▪Unicorn whale	3.4-6.2	Shallow	NT						
	Delphinapterus leucas	▪Beluga ▪White whale	3-5.5	Shallow	NT (CR)	●					
Delphinidae		**Dolphins**									
	Cephalorhynchus commersonii	▪Commerson's dolphin ▪Piebald dolphin	1.4-1.5	Shallow	DD						
	Cephalorhynchus eutropia	▪Chilean dolphin ▪Black dolphin ▪White-bellied dolphin	0.17	Shallow	NT						
	Cephalorhynchus heavisidii	▪Heaviside's dolphin ▪Benguela dolphin	0.18	Shallow	DD						
	Cephalorhynchus hectori	▪Hector's dolphin	1.2-1.5	Shallow	EN (CR)						

Table 16: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Steno bredanensis	▪Rough-toothed dolphin	2.2-2.6	Shallow	LC		●		●	●	●
	Sousa teuszii[8]	▪Atlantic humpback dolphin ▪Teusz's dolphin ▪plumbea	2-2.4	Shallow	VU						
	Sousa plumbea	▪Indian humpback dolphin		Shallow	???						
	Sousa chinensis	▪Pacific humpback dolphin ▪Indo-pacific humpbacked dolphin ▪Chinese white dolphin ▪Eastern Taiwan Strait humpback dolphin	2-3.2	Shallow	NT (CR)					●	●
	Sotalia fluviatilis	▪Estuarine dolphin ▪Gray dolphin ▪Guianian river dolphin ▪Tucuxi	1.4-2.2	Shallow	DD						
	Tursiops truncatus	▪Common bottlenose dolphin ▪bottle-nosed dolphin ▪bottlenose dolphin ▪Bottlenosed dolphin	2.3-3.8	Shallow	LC (EN)		●	●	●	●	●

[8] The taxonomy of the Sousa genus is complicated and disputed. As many as five species have been proposed: S. chinensis (Humpback Dolphin, Indo-Pacific Humpback Dolphin, Pacific Humpback Dolphin, Chinese White Dolphin); S. plumbea (Indian Humpback Dolphin, Plumbeous Humpback Dolphin); S. teuszi (Atlantic Humpback Dolphin); S. lentiginosa;S. borneensis

Table 17: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Tursiops aduncus	▪Indo-pacific bottlenose dolphin ▪Indian Ocean bottlenose dolphin	<2.6	Shallow	DD					●	●
	Stenella attenuata	▪Pantropical spotted dolphin ▪Bridled dolphin ▪Narrow-snouted dolphin	1.9-2.6	Shallow	LC		●		●	●	●
	Stenella frontalis	▪Atlantic spotted dolphin ▪Bridled dolphin	2-2.3	Shallow	DD		●		●		
	Stenella longirostris	▪Spinner dolphin ▪Long-beaked dolphin ▪Long-snouted dolphin ▪Eastern spinner dolphin	1.7-2.4	Shallow	DD (VU)		●		●	●	●
	Stenella clymene	▪Clymene dolphin ▪Atlantic spinner dolphin ▪Helmet dolphin	1.9-2.0	Shallow	DD		●		●		
	Stenella coeruleoalba	▪Striped dolphin ▪Euphrosyne dolphin	1.9-2.6	Shallow	LC		●		●	●	●

Table 18: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Delphinus delphis	▪Common Dolphin ▪Short-beaked common dolphin ▪Atlantic dolphin ▪Pacific dolphin ▪Saddle-backed dolphin ▪Short-beaked Saddleback dolphin ▪Black sea common dolphin ▪Meaditerranean common dolphin	1.5-2.2	Shallow	LC (VU, EN)		●	●	●		
	▪*Delphinus capensis capensis* ▪*Delphinus capensis tropicalis*	▪Long-beaked common dolphin ▪Arabian common dolphin	1.9-2.6	Shallow	DD						●
	Lagenodelphis hosei	▪Fraser's dolphin ▪Sarawak dolphin	2.2-2.6	Shallow	DD		●		●	●	●
	Lagenorhynchus albirostris	▪White-beaked dolphin	2.4-3	Shallow	LC	●		●			
	Lagenorhynchus acutus	▪Atlantic white-sided dolphin	2.2-2.7	Shallow	LC		●	●			
	Lagenorhynchus obliquidens	▪Pacific white-sided dolphin	1.7-2.4	Shallow	LC						
	Lagenorhynchus obscurus	▪Dusky dolphin	1.9-2.2	Shallow	DD						

Table 19: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Lagenorhynchus australis	▪Peale's dolphin ▪Blackchin dolphin	2.1	Shallow	DD						
	Lagenorhynchus cruciger	▪Hourglass dolphin	1.5-1.9	Shallow	LC						
	Lissodelphis borealis	▪Northern right-whale dolphin	2.2-3	Shallow	LC						
	Lissodelphis peronii	▪Southern right-whale dolphin	2.2-2.4	Shallow	DD						
	Grampus griseus	▪Risso's dolphin	2.6-3.8	Shallow	LC		●	●	●	●	●
	Peponocephala electra	▪Melonheaded whale	2.2-2.7	Shallow	LC		●		●	●	●
	Feresa attenuate	▪Pygmy killer whale ▪Slender Blackfish	2-2.9	Shallow	DD		●		●	●	●
	Pseudorca crassidens	▪False killer whale	3.5-5.9	Shallow	DD		●	●	●	●	●
	Orcinus orca	▪Killer whale	4.6-9	Shallow	DD	●	●	●	●	s●	●

Table 20: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
	Globicephala melas *Globicephala edwardii* ▪*Globicephala leucosagmaphora* ▪*Globicephala melaena*	▪Long-finned pilot whale	3.5-7.6	Shallow	DD		●		●	●	●
	Globicephala macrorhyncus	▪Short-finned pilot whale ▪Pacific pilot whale	5.1-6.7	Shallow	DD			●			
	Orcaella brevirostris	▪Ayeyarwady River Irrawaddy dolphin ▪Mahakam River Irrawaddy ▪Malampaya Sound Irrawaddy dolphin ▪Mekong River Irrawaddy dolphin ▪Songkhla Lake Irrawaddy dolphin ▪Snubfin dolphin	2.2-2.7	Shallow	VU (CR)						
	Orcaella heinsohni	▪Australian snubfin dolphin		Shallow	NT						

Table 21: Suborder Odontocete (Continued)

Family	Species	Common Name(s)	Size (m)	Diving Behaviour	IUCN Status	S1	S2	S3	S4	S5	S6
Phocoenidae		**Porpoise**									
	Neophocaena phocaenoides	▪Finless porpoise ▪Black finless porpoise ▪Finless black porpoise ▪Yangtze Finless porpoise	1.4-1.9	Shallow	VU (EN)						●
	Phocoena phocoena	▪Harbour porpoise ▪Common porpoise ▪Baltic Sea Harbour porpoise ▪Black Sea Harbour porpoise	1.9	Shallow	LC (EN, CR)	●		●			
	Phocoena sinus	▪Golfa de California porpoise ▪vaquita	.4-.5	Shallow	CR						
	Phocaena dioptrica	▪Spectacled porpoise		Shallow	DD						
	Phocoena spinipinnis	▪Black porpoise ▪Burmeister's porpoise	0.150	Shallow	DD						
	Phocoenoides dalli *Phocoenoides truei*	▪Dall's porpoise ▪White-flanked porpoise	1.9-2.4	Shallow	LC						

4 Summary

Under the Exploration and Production (E&P) Sound and Marine Life Programme, a research study was carried out on the feasibility of the Active Acoustic Monitoring (AAM) of marine mammals. The purpose of such monitoring would be to detect marine mammals in those ocean areas where E&P activities are being conducted, in order to allow due diligence in mitigating any potential impact of these E&P operations. The study did not include any direct experimentation.

The AAM study encompassed multiple work components. First, the problem domain was delineated in an overview of offshore E&P activities and of the ocean environments in which they are conducted. To make the analysis more concrete, six specific ocean areas of relevance to E&P were selected and their properties described. Next, the potential performance of AAM was investigated via a parametric study of the sonar equation, incorporating available knowledge of sonar technology and environmental effects (e.g., high-frequency backscattering from the ocean boundaries). This part of the study was intended to identify any fundamental limitations to AAM as imposed by technology or by the basic physics of the problem, and also to pinpoint those sonar features that are of key importance for AAM. Special effort was dedicated to investigating the target strength of marine mammals, as this is an area in which scientific knowledge is sparse at present. The parametric analysis included several generic examples, and was also applied to the six specific ocean areas; however, computer modeling of the six environments was beyond the scope of the study.

This report (Volume IV) provides a description of six environments relevant to E&P Operations with unique acoustic characteristics. The acoustic description is included for each environment. In addition, a survey of marine mammals including their use of the six E&P environments is included. For each species, the IUCN (International Union for Conservation of Nature) status is included as an indication of species health.

The potential performance of AAM systems in these six environments is investigated in the potential performance assessment (Volume V), and is summarised in Volume 1.

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Survey of Active Acoustic Monitoring (AAM) Technologies: Volume IV: E&P Environments and Marine Mammals

4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

J. Theriault; E. MacNeil; B. Maranda; L. Gilroy; J. Hood; Canadian Seabed Research Ltd.

5. DATE OF PUBLICATION (Month and year of publication of document.)	6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)	6b. NO. OF REFS (Total cited in document.)
March 2010	84	0

7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

External Client Report

8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

International Association of Oil and Gas Producers (OGP)
Joint Oil and Gas Industry Programme on Sound and Marine Life (JIP 22)

9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.) RFP JIP08-05	9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.) JIP22 08-05
10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Atlantic ECR 2010-043	10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

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