Potential Waterborne Hazards from the FSO Safer, Red Sea

Request Summary

Request	Potential hazards from the FSO Safer oil tanker in the Red Sea
Employment	Contingency Planning
Hazards	Oil spill/Waterborne Hazard
Location	Red Sea IVO 15.118° N / 42.5993° E
Weather	Varies
Incident Date & Time	Varies
Executive Summary	• Waterborne effects vary based on season and weather. • During winter months, transport is generally to the north (see slides following) • During summer months, transport is generally to the south, then east after exiting the Bab al-Mandab Strait

Executive Summary

Current estimates of effects :

- Waterborne effects from an oil spill under winter conditions will primarily affect the Arabian Peninsula to the north of the FSO Safer over the short term (two weeks). Over the summer, the Arabian Peninsula to the south of the Safer will primarily be affected, with significant stranded oil in Yemen.
- Longer duration simulations (one month) show that oil could affect the Bab al-Mandab Strait and then move generally eastward, paralleling the coast of Yemen.
- Stochastic simulations suggest high probability of impact in summer scenario east and south of Safer. Lower probability of impact farther south and west (see slide for details).
- Weather conditions in winter (Oct. – Apr.) tend to push effects north along the coast, affecting NW Yemen and SW Saudi Arabia. Summer conditions (Jun. – Sep.) push effects south and east, into Yemen and Gulf of Aden.

General Caveats

For all the analyses that follow, please keep in mind that:

1. Intelligence on the FSO Safer and its contents are currently limited. Estimates of amount of oil, type of oil, condition of oil, physical condition of the boat, etc. are highly uncertain.

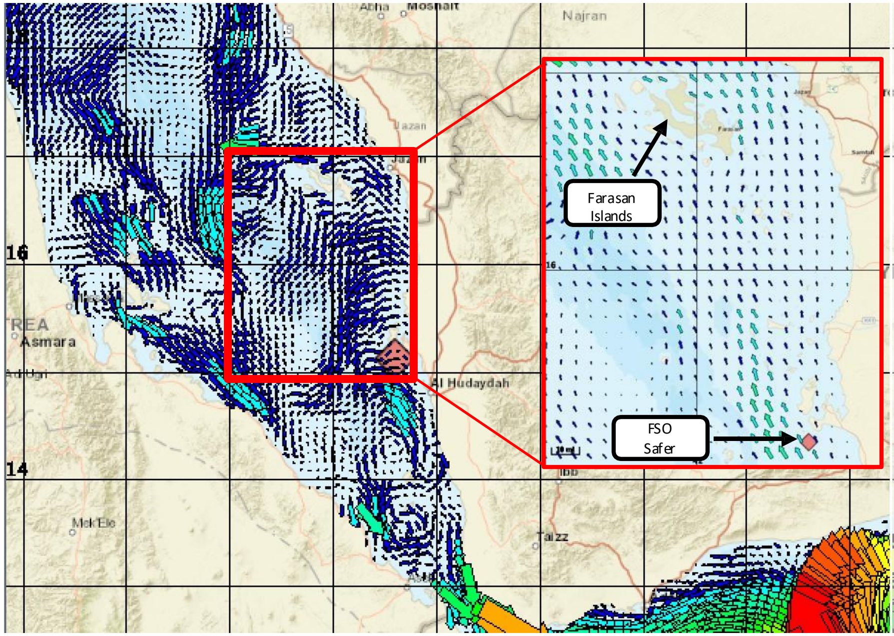
2. There are thousands of different scenarios that could occur (especially true for a waterborne release scenario). It is not feasible to model all scenarios, and there is no reason to think that what will actually occur in the event of an incident will match what is modeled here. Therefore, modeling results should instead be used to provide an idea of the possible types of threats that **might** occur.

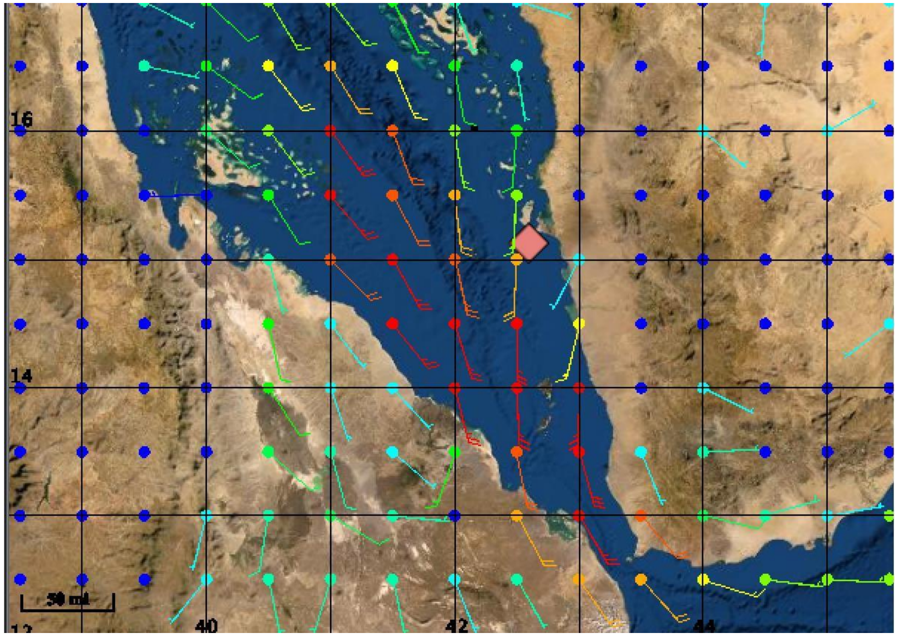
3. Building on Point #2, in the event of a real incident occurring, modeling can be updated to more realistically reflect the actual incident, assuming there is sufficient information.

Two Week Simulations

- A hypothetical release of 5 million gallons of crude oil into the Red Sea from the vessel were modeled.
- The Marib-type crude oil on the vessel is considered a light crude oil. For this simulation, a medium crude oil with a lower aromatic fraction was used. This simulates some loss of lighter material from oil aging, but also provides a crude oil that is relatively mobile but somewhat resistant to degradation or evaporation.
- A constant release rate over a 7-day period was implemented for the simulation.
- Historical wind and hydrodynamic forecast information from February (winter) or July and August (summer) were used to represent typical seasonal weather conditions.
- This forecast covers a 14-day period.
- These models do not account for any emergency response actions taken to boom or remove the oil.

Model Forcing Data Summary





HYCOM currents for the Horn of Africa region were used for the hydrodynamic forcing.

Resolution: 0.08 degree, 3 hours (see example above).

Currents at the release site are persistent to the north/northwest. Divergence and some tidal shifting with much lower magnitude currents are observed at the northernmost edge of the projected oil plume, beginning south of the Farasan Islands.

GFS forecast winds were used for the meteorological forcing of the oil spill simulation.

Resolution: 0.5 degree, 3 hours (above).

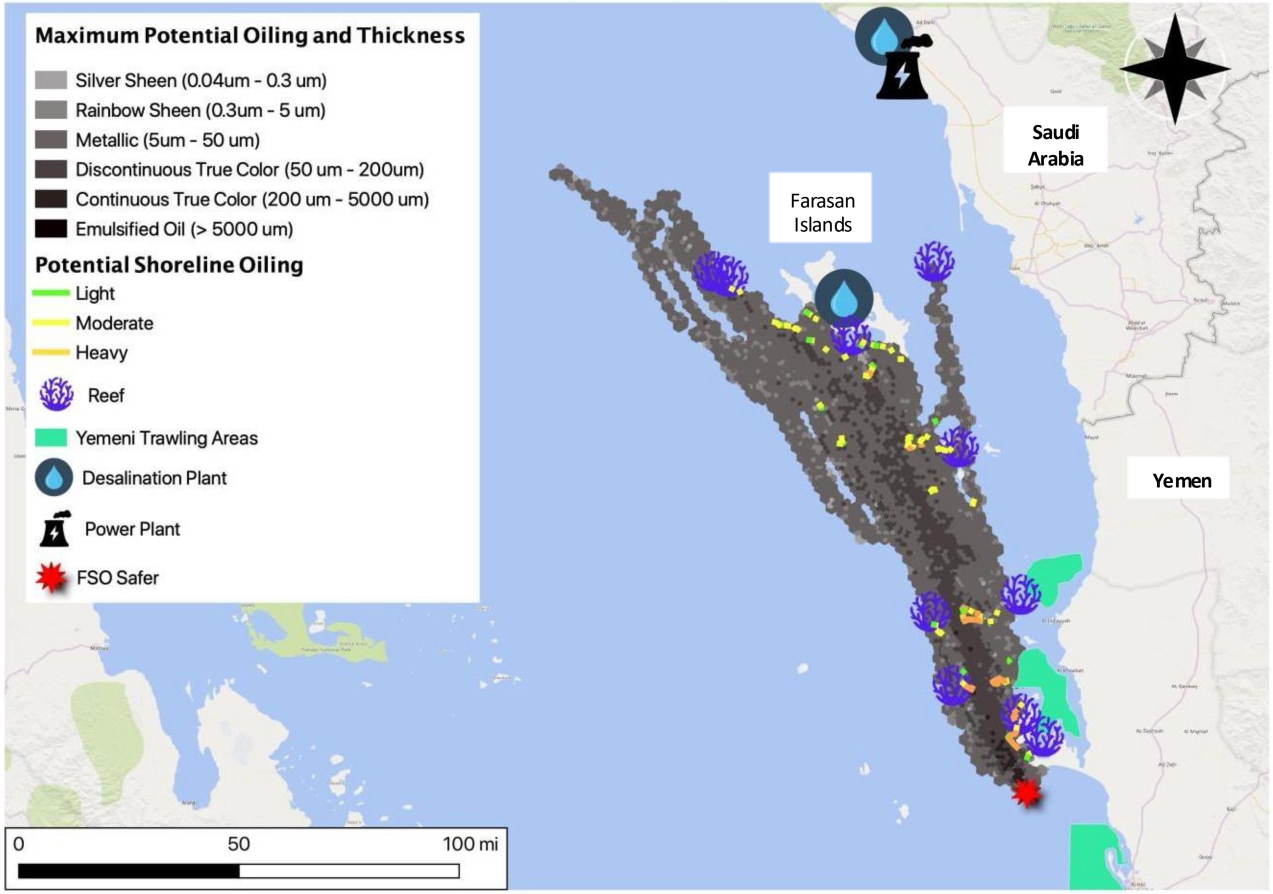
Persistent 18-23 knot southerly winds were forecasted during the first three days of the simulation, driving the oil plume to the north. Between days 5-7, the wind field weakened, becoming variable. On day 12, winds near the Farasan Islands at the leading edge of the plume weakened.

Waterborne Summary: Winter; 2 Week Simulation

- The total forecast covers 14 days after the initial release started.
- The overall material transport extends approximately 175 miles from the current location of the FSO Safer to the northwest.
- The released material impacts an area of approximately 3700 square miles over the course of the 14-day simulation.
- Shoreline material stranding and retention significantly impact the islands off the coast of Yemen and Saudi Arabia. An estimated 20% of the material is retained at the shoreline. 35% of the material is predicted to evaporate and 45% is predicted to remain in the water column.
- Approximately 32 miles of shoreline are potentially impacted by the released oil in this 14-day simulation period.

Waterborne Hazard Forecast Summary: Winter

Total area covered and maximum thickness over the course of the entire simulation.



- The oil travels approximately 175 miles to the north-northwest over the 14-day simulation.
- 3700 mi^2 of water surface is potentially impacted by oil over the entire simulation.
- Heavy and moderate potential surface oiling are observed during the entire simulation.
- An estimated 32 miles of shoreline would potentially be impacted by stranded oil.
- 10 major reefs are potentially subject to direct oiling.
- 2 of the major Yemeni Trawling Areas in the Red Sea are potentially impacted (256 square miles).
- The Farasan Islands and the desalination plant would potentially be impacted by the spilled oil.

Potential Reef Impact Summary: Winter

The Red Sea has some of the highest diversity of coral reefs in the world with over 300 species of coral. There are more than 220 species in the region forecasted to be impacted by oil under the prevailing weather and current conditions.

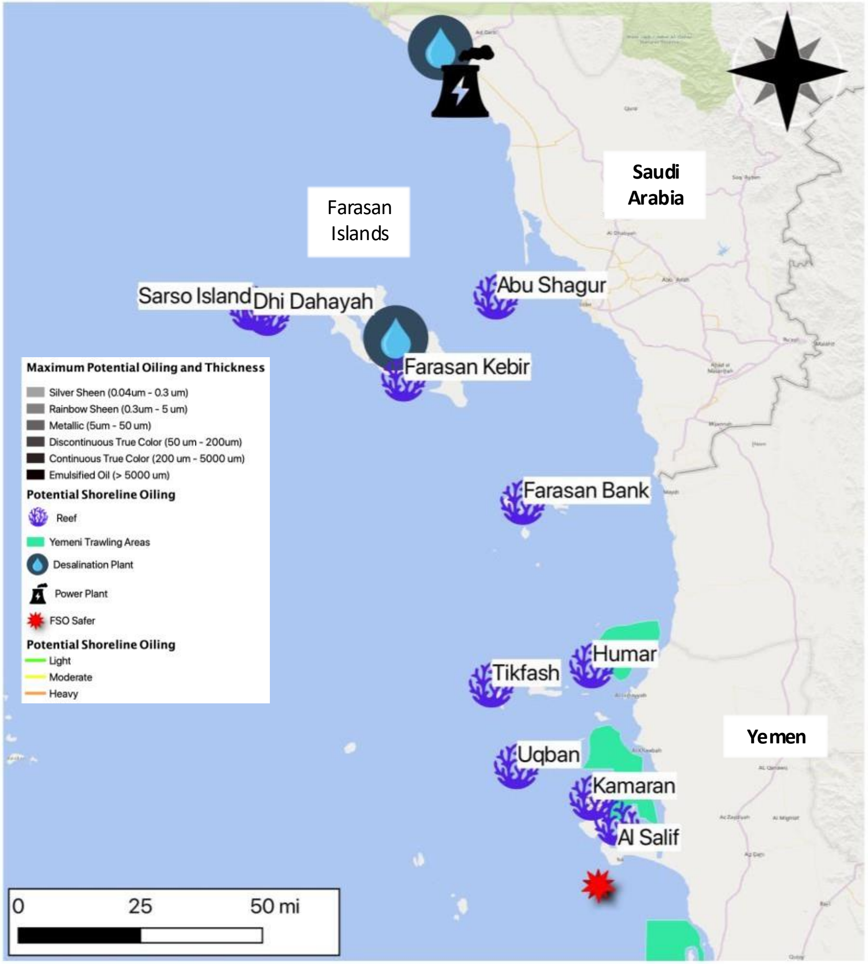
Types of Reefs

Major reef types in the Southern Red Sea in the potentially impacted area:

- Fringing reefs, the most common type of reef which grow near coastlines.
- Ring reefs, rings of coral that create protected lagoons.
- Pillar reefs: Primarily composed of the threatened pillar coral species.

Potential Immediate Impacts

- Within a 14-day period, 10 major coral reefs are potentially impacted by oil.
- Dispersed or emulsified oil could smother coral, sponges, crustaceans, and mollusks, particularly in the shallow fringing reef systems common to the region.
- Floating oil impairs coral's ability to photosynthesize light and kill floating microorganisms such as zooplankton.



Potential Infrastructure Impact Summary: Winter

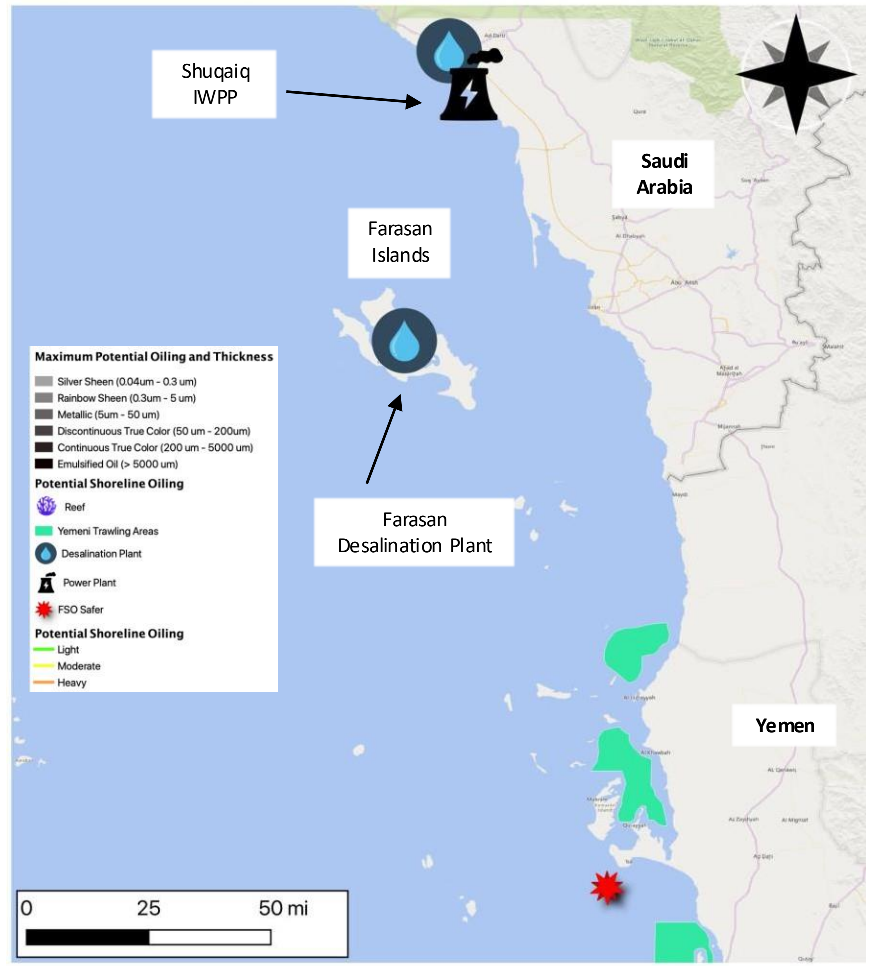
There are two desalination plants and one power plant in the vicinity of the predicted oil plume.

Potential Immediate Impacts:

- Within 14 days, oil could affect the Farasan Seawater Reverse Osmosis Desalination Plant. This plant provides fresh water to residents of Farasan Islands, Saudi Arabia.

Potential Further Impacts:

Beyond the 14-day simulation period, transport of the remaining oil north past the Farasan Islands poses a potential to impact the Shuqaiq 2 Independent Water & Power Project (IWPP). This complex supplies electricity and water to 2.5 million people in Saudi Arabia (approx. 7% of population).



Resources Potentially Impacted: Winter

MAJOR REEFS			
Name	**Country**	**Type**	**Impact**
Al Salif	Yemen	Coastal Fringing	Fringing systems are found in shallow waters, providing conditions to support seagrasses. These areas are important for fisheries nurseries. There is moderate to high density coral diversity (221 species) along the Yemeni Coast and north into Saudi Arabia. The Farasan Islands, are a small group of coral islands, are a Marine Sanctuary, are critical nesting grounds for green (endangered) and hawksbill (critically endangered) sea turtles.
Kamaran	Yemen	Fringing	
Uqban	Yemen	Fringing	
Tikfash	Yemen	Fringing	
Humar	Yemen	Fringing	
Farasan Bank	Yemen	Fringing/Pillar/Ring	
Farasan Kebir	Saudi Arabia	Fringing	
Dhi Dahayah	Saudi Arabia	Fringing	
Sarso Island	Saudi Arabia	Fringing	
Abu Shagur	Saudi Arabia	Fringing	
FISHERIES			
Trawling Grounds	Yemen	----	The Red Sea accounts for >10% of Yemen's fisheries production. Artisanal fishing is the primary source of income for the coastal community along the Red Sea. There are an estimated 850K tons of fisheries stocks along the Yemeni Red Sea Coast. Major species: Cuttlefish, Shrimp, Rock Lobsters, Sardines, Mackerel, Shark
DESALINATION PLANTS			
Farasan Plant	Saudi Arabia	Reverse Osmosis	Disruption to water supply 790,000 gallons/day to 20,000 people..
Shuqaiq Plant	Saudi Arabia	Reverse Osmosis	Disruption of water supply of 48 million gallons/day to 2.5 million people.
POWER PLANTS*			
Shuqaiq Plant	Saudi Arabia	Crude Oil Fired	Potential disruption of power supply from the 850 MW plant to 2 million people.

*The Jizan IGCC Power Plant is nearing completion of construction. This plant is not depicted in the analysis, but would potentially be impacted from large spill.

Potential Shoreline Impact: Winter

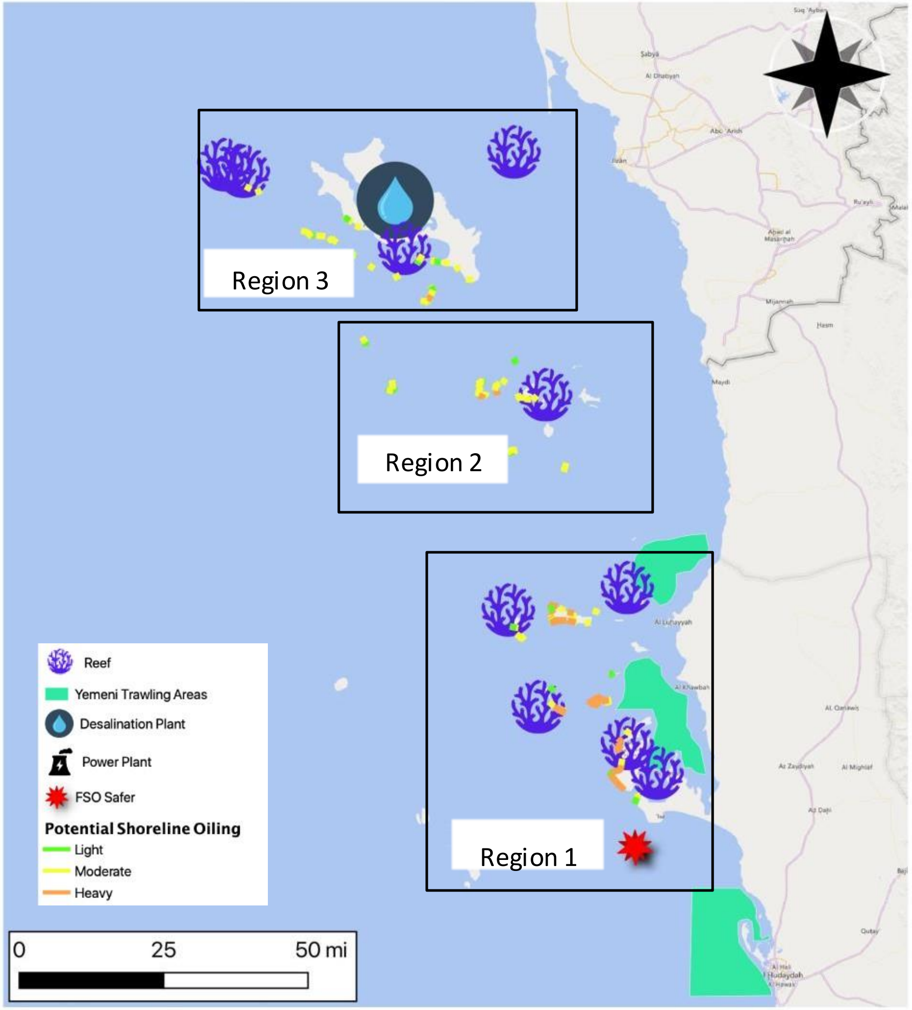
Approximately 32 miles of shoreline are predicted to be impacted by oiling over the course of the 14-day simulation. There are three potential regions of shoreline oiling:

Region 1: 21.7 miles of potential shoreline oiling. Includes key Yemeni fisheries, reefs, and Kamaran, Uqbun, Al Bawdi, Jazirat Antufash, Al Khawtamah, Al Urmar, and Qusur Islands.

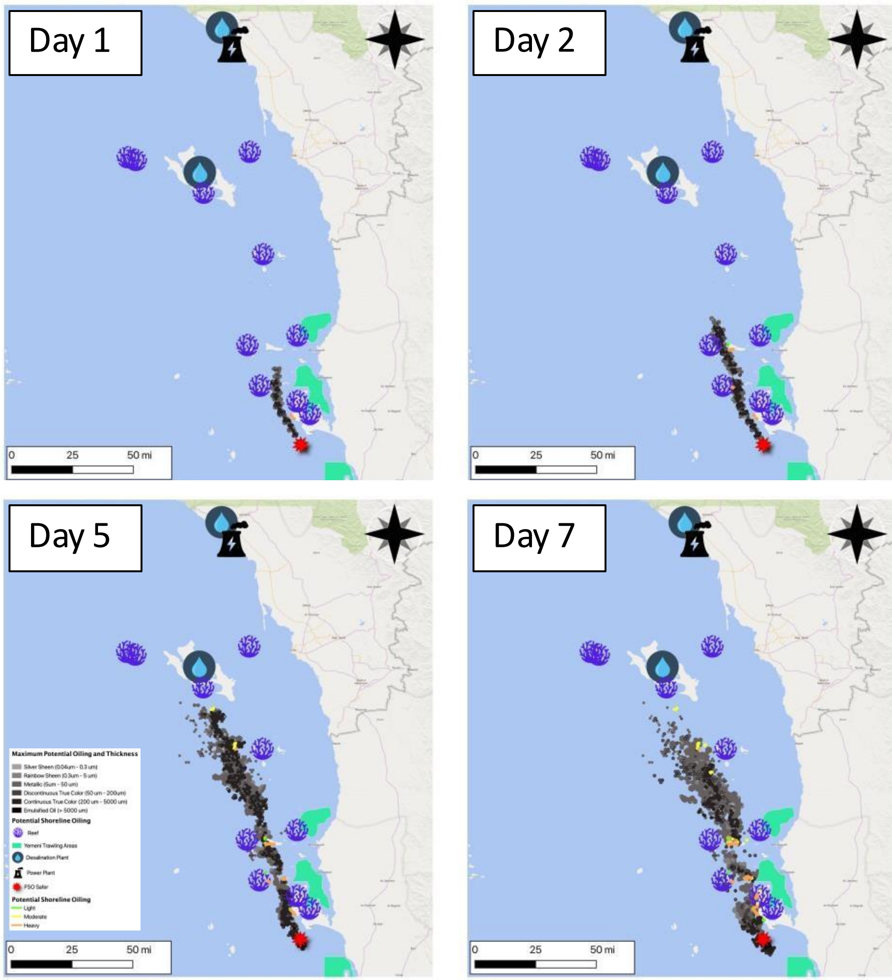
Region 2: 4 miles of potential shoreline oiling. Includes Jazirat Sumayr, Jazirat Sana, and J Madjun Islands.

Region 3: 6.3 miles of potential shoreline oiling. This region encompassed the Farasan Islands, a Marine Protected Area, which provides critical habitat for endangered sea turtle species.

Coral-derived sand is the predominant shoreline material for the islands that are potentially impacted in the oil spill simulation.
Immediate removal of contaminated sand would be required to prevent migration of stranded oil deeper into the sand. Excavation and high-pressure washing systems are the primary clean-up tools used on this type of oiled shoreline.



Winter Oil Plume Evolution: Week 1



Summary of Location and Potential Impacts

Day 1

- **Trajectory:** Transport to the NNW; oil plume roughly 35 miles long
- **Reefs:** Kamaran Reef
- **Fisheries:** Kamaran Fishing Region
- **Shoreline:** 0.1 miles shoreline on Kamaran Island potentially impacted

Day 2

- **Trajectory:** Transport to the NNW; oil plume roughly 55 miles long
- **Reefs:** Al Salif, Kamaran, Uqban, Tiqfash reefs
- **Fisheries:** Kamaran Fishing Region impacted
- **Shoreline:** 0.8 miles of shoreline over Kamaran, Uqban, and Jazirat Antufash Islands potentially impacted

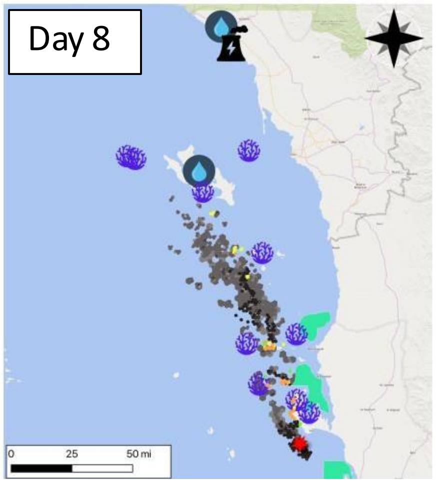
Day 5

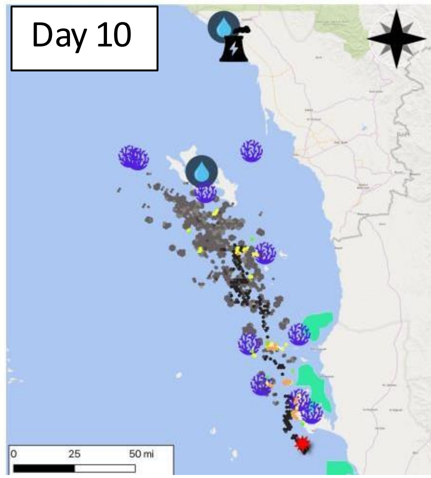
- **Trajectory:** Transport to the NNW; oil plume roughly 90 miles long
- **Reefs:** Farasan Bank
- **Fisheries:** Kamaran Fishing Region impacted
- **Shoreline:** 5 miles of shoreline; Al Bawdi Island potentially impacted

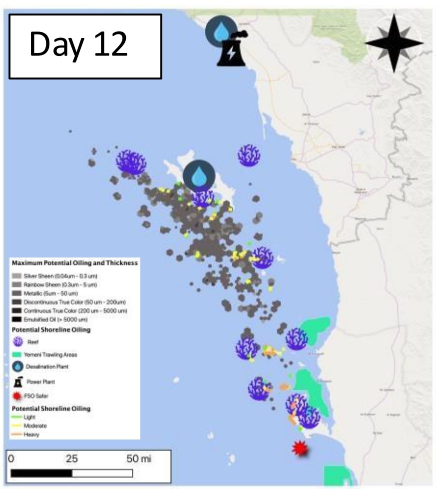
Day 7: Tides and Winds Change, Causing a Shift to the South

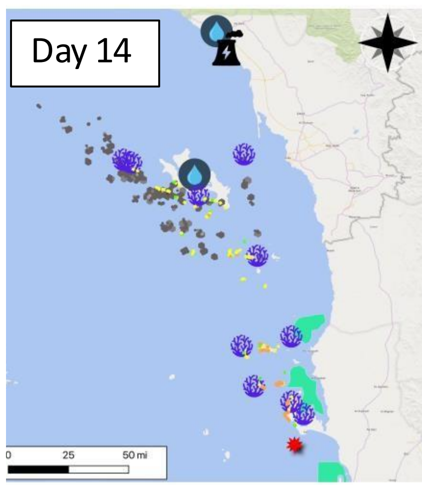
- **Trajectory:** Transport to the southeast, oil plume roughly 100 miles long
- **Reefs:** Southern fringe of Farasan Kebir Reef
- **Fisheries:** Kamaran Fishing Region, approaching Tiqfash Region.
- **Shoreline :** 22.3 miles of shoreline; Qusur and Jazirat Sanaa Islands potentially impacted.

Winter Oil Plume Evolution: Week 2









Summary of Location and Potential Impacts

Day 8

- **Trajectory:** Transport slows; oil plume extends 122 miles from release
- **Reefs:** Kamaran Reef
- **Fisheries:** Kamaran Fishing Region impacted
- **Shoreline:** 23 miles of shoreline; Al Urmar Island potentially impacted

Day 10

- **Trajectory:** Slower transport to the NNW; plume extends 137 miles from release
- **Reefs:** Al Salif, Kamaran, Uqban, Tikfash, Farasan Bank, Farasan Kebir
- **Fisheries:** Kamaran Fishing Region impacted
- **Shoreline:** 27 mile of shoreline; Al Khawtamah and Jazirat Sumayr Islands potentially impacted

Day 12

- **Trajectory:** Transport to the NNW; oil plume roughly 163 miles long
- **Reefs:** Al Salif, Kamaran, Uqban, Tikfash, Farasan Bank, Farasan Kebir
- **Fisheries:** Kamaran, western edge of Tiqfash Fishing Regions impacted
- **Shoreline:** 29.5 miles of shoreline; J Madjun and Farasan Islands potentially impacted

Day 14

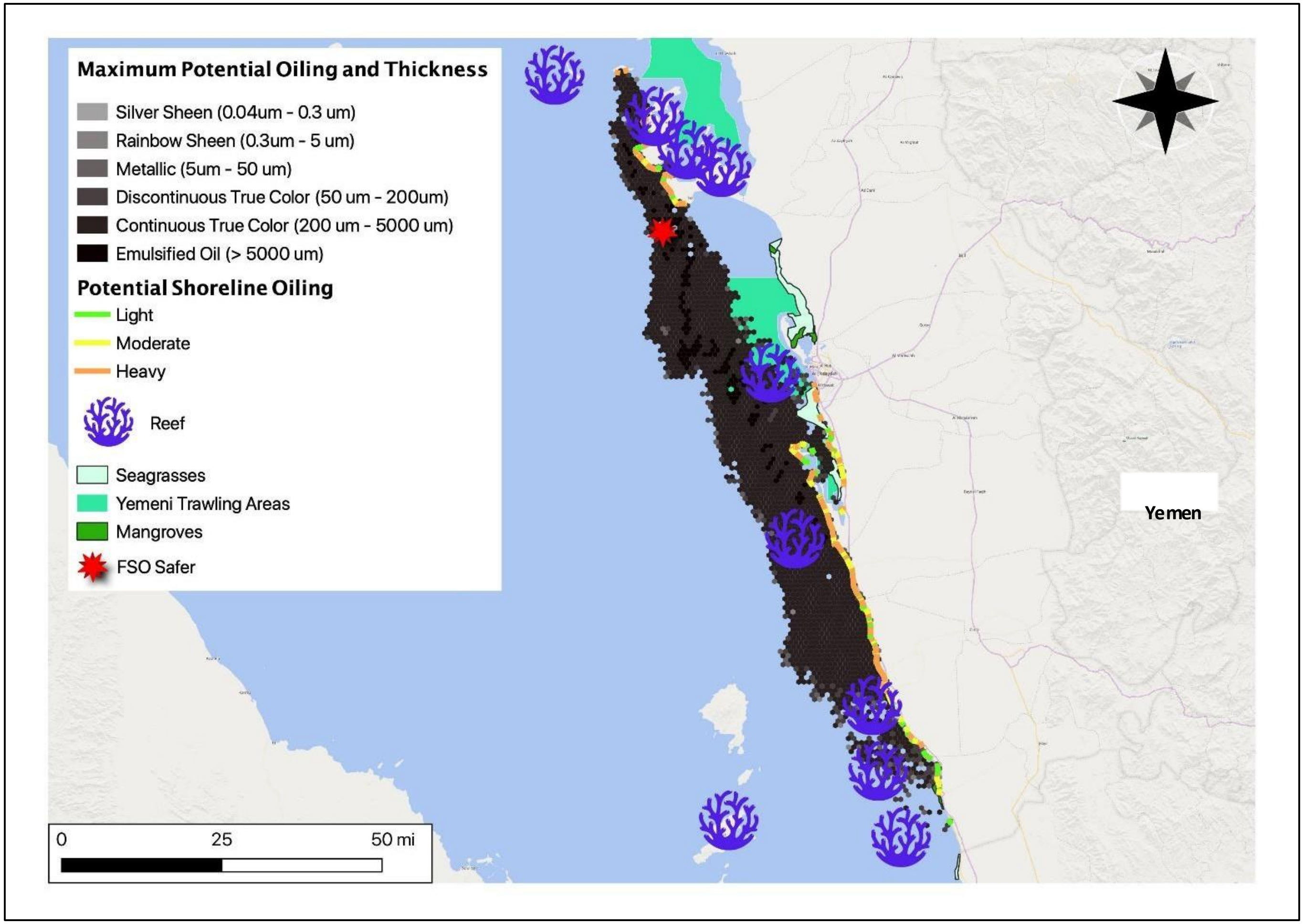
- **Trajectory:** Transport to the NNW; oil plume roughly 180 miles long
Reefs: Al Salif, Kamaran, Uqban, Tikfash, Farasan Bank, Farasan Kebir, Sarso Island, Dhi Dahayah, Abu Shagur
- **Fisheries:** Kamaran, western edge of Tiqfash Fishing Regions impacted
- **Shoreline:** 32 miles of shoreline potentially impacted by oil

Waterborne Summary: Summer; 2 Week Simulation

- The total forecast covers 14 days after the initial release started.
- The overall material transport extends approximately 103 miles from the current location of the FSO Safer to the southeast.
- The released material impacts an area of approximately 1472 square miles over the course of the 14-day simulation.
- Shoreline material stranding and retention significantly impact the coast of Yemen. Approximately 56% of the material is retained at the shoreline, while 39% of the material is predicted to evaporate, and 5% remains in the water after 14 days.
- Approximately 87 miles of shoreline are potentially impacted by the released oil.
- Three major fishing grounds are potentially impacted by oil.

Waterborne Hazard Forecast Summary: Summer

Total area covered and maximum thickness over the course of the entire simulation.



- The oil travels approximately 103 miles to the southeast over the 14-day simulation.
- 1472 mi^2 of water surface is potentially impacted by oil.
- Heavy and moderate potential surface oiling is observed during the entire simulation.
- Approximately 87 miles of shoreline would potentially be impacted by stranded oil.
- 5 major reefs are potentially subject to direct oiling.
- 3 of the major Yemeni Trawling Areas in the Red Sea are potentially impacted (367 square miles).

Potential Fisheries Impact Summary: Summer

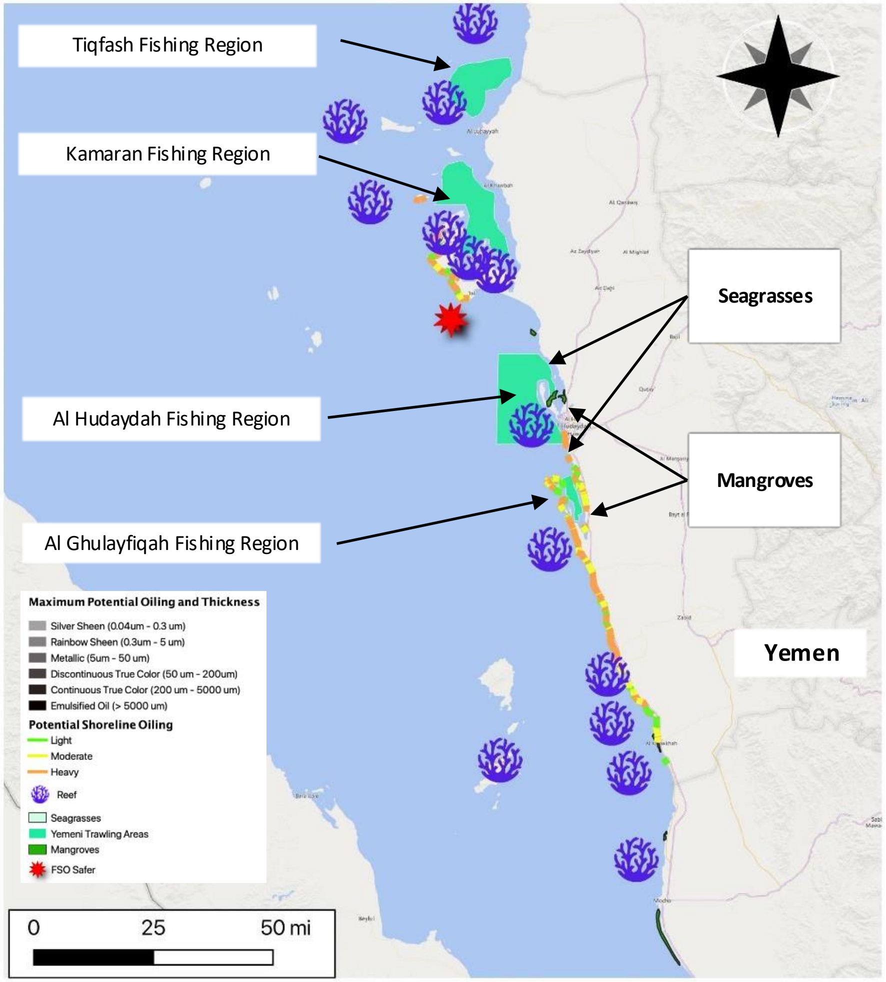
Within 14 days, up to 367 mi² of Yemen's major trawling grounds in the Red Sea could be impacted by oil. Impacts in the Kamaran Fishing Region are forecasted within two days of the hypothetical oil spill. Major fishing grounds around Al Hudaydah are potentially impacted by the end of the first week. Within 10 days, the major fisheries around Al Ghulayfiqah are also forecasted to be impacted under typical summer wind and current conditions.

These three regions represent >75% of the major trawling grounds along the Yemeni Red Sea coast, which in total accounts for 10% of Yemen's total fish production.

Types of Fisheries:

- Trawling & Gillnet
- Important Commercial Species in the Red Sea:
  - Penaeid shrimp, cuttlefish, rock lobster, Indian mackerel, Spanish mackerel, yellowfin tuna, snapper, jackfish, lizard-fish, grouper, rabbitfish, sea-bream, sharks.

Coastal mangroves provide vital fish nursery habitat and help to maintain the water clarity needed for active healthy reef ecosystems. Oiling of these sensitive regions can disrupt local fisheries, with full recovery times on the order of decades.



Potential Reef Impact Summary: Summer

The Red Sea has some of the highest diversity of coral reefs in the world with over 300 species of coral. There are more tha 220 species in the region forecasted to be impacted by oil unde the prevailing weather and current conditions.

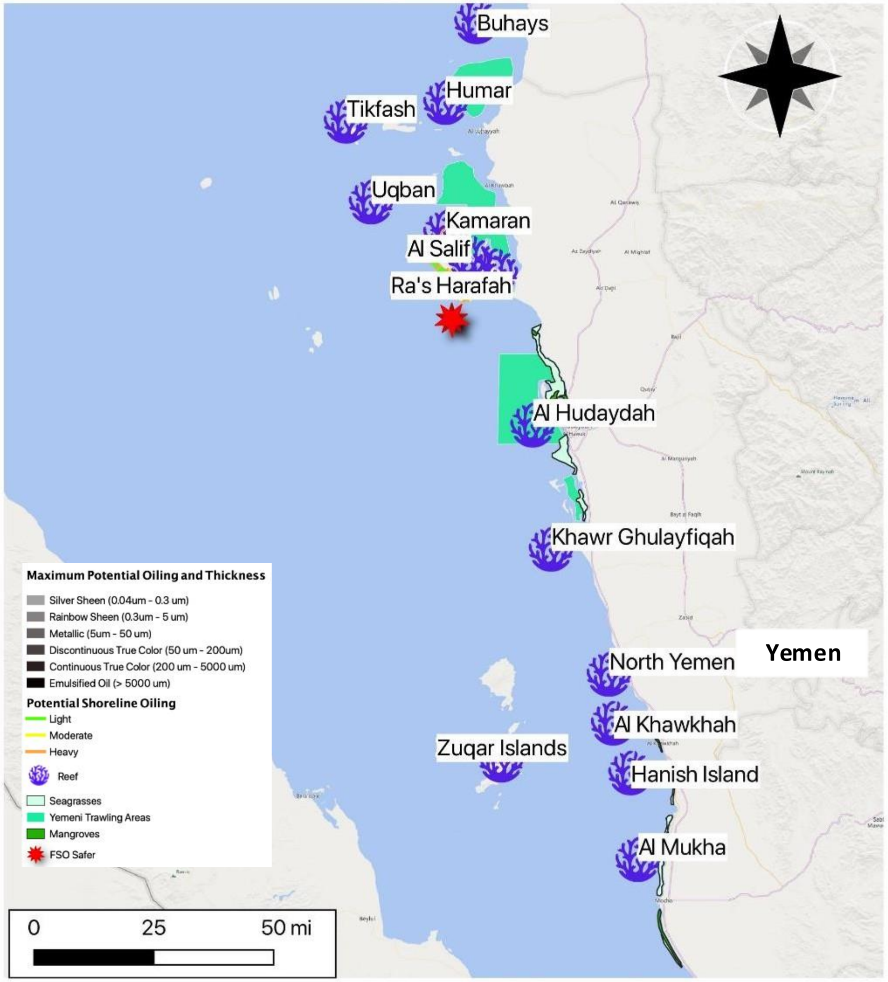
Types of Reefs

Major reef types in the Southern Red Sea in the potentially impacted area:

- Fringing reefs, the most common type of reef which grow near coastlines.
- Ring reefs, rings of coral that create protected lagoons.
- Pillar reefs: Primarily composed of the threatened pillar coral species.

Potential Immediate Impacts

- Within a 14-day period, 5 major coral reefs are potentiall impacted by oil.
- Dispersed or emulsified oil could smother coral, sponges, crustaceans, and mollusks, particularly in the shallo fringing reef systems common to the region.
- Floating oil reduces water clarity, impeding photosynthesis Floating oil can also adversely impact the microorganism that serve as the foundation of the marine food web reducing food availability to fish and marine organisms.



Resources Potentially Impacted: Summer

MAJOR REEFS			
Name	**Country**	**Type**	**Impact**
Kamaran	Yemen	Fringing	Fringing systems are found in shallow waters, providing conditions to support seagrasses. These areas are important for fisheries nurseries. Non-reef coral communities provide additional critical habitat for fish and other commercially important sea-life. There is moderate to high density coral diversity (221 species) along the Yemeni Coast, with diversity towards the south.
Al Hudaydah	Yemen	Non-reef coral community	
Khawr Ghulayfiqah	Yemen	Non-reef coral community	
North Yemen	Yemen	Fringing/Patch/Non-reef coral community	
Al Khawkhah	Yemen	Non-reef coral community	
FISHERIES			
Trawling Grounds	Yemen	----	The Red Sea accounts for >10% of Yemen's fisheries production. Artisanal fishing is the primary source of income for the coastal community along the Red Sea. There are an estimated 850K tons of fisheries stocks along the Yemeni Red Sea Coast. Major species: Cuttlefish, Shrimp, Rock Lobsters, Sardines, Mackerel, Shark
DESALINATION PLANTS			
There are no functional desalination plants in the potential region of oil impact. The desalination plant at Mokha, which was damaged in 2016, is approximately 20 miles south of the predicted southern most extent of the oil plume after 2 weeks. Continued transport to the south, expected based upon the prevailing wind and currents, would likely reach Mokha. Based on its current status, this incident would not have an effect.			
POWER PLANTS			
There are no identified power plants in the potential region of impact.			

Potential Shoreline Impact Summary: Summer

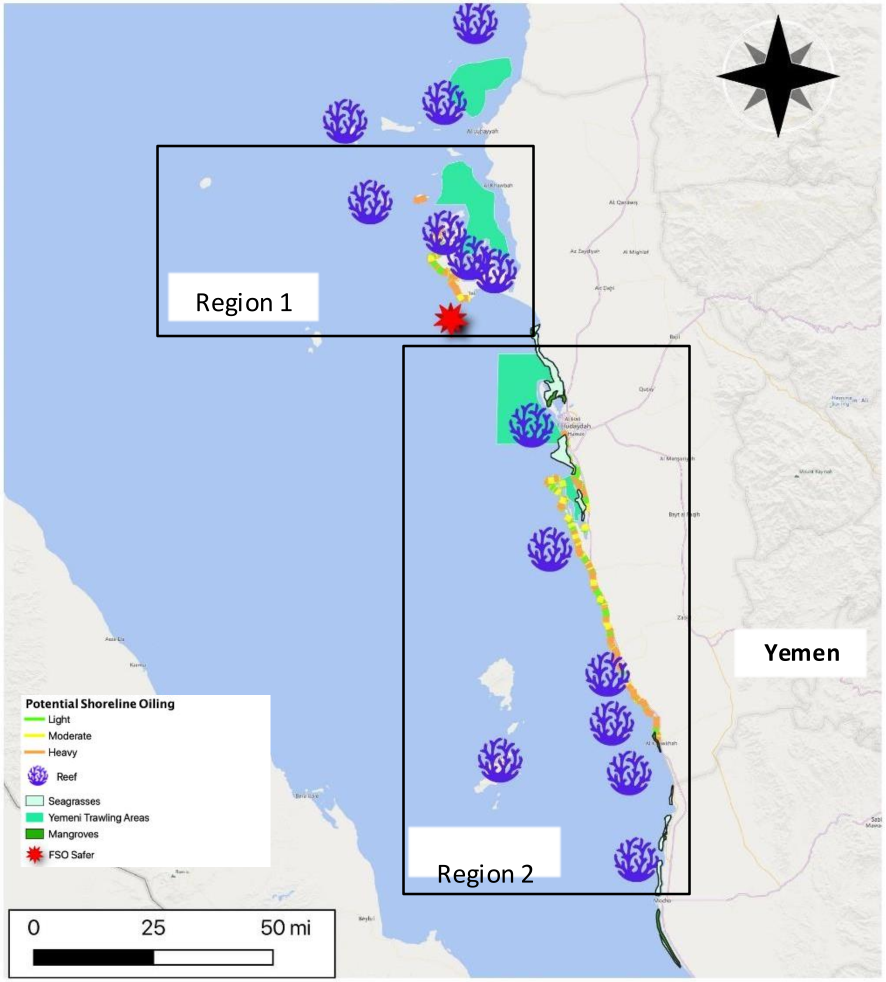
Approximately 87 miles of shoreline are predicted to be impacted by oil over the course of the 14-day simulation. There are two potential regions of shoreline oiling:

Region 1: 20 miles of potential shoreline oiling. Includes key Yemeni fisheries, reefs, and Kamaran and Al Bawdi Islands.

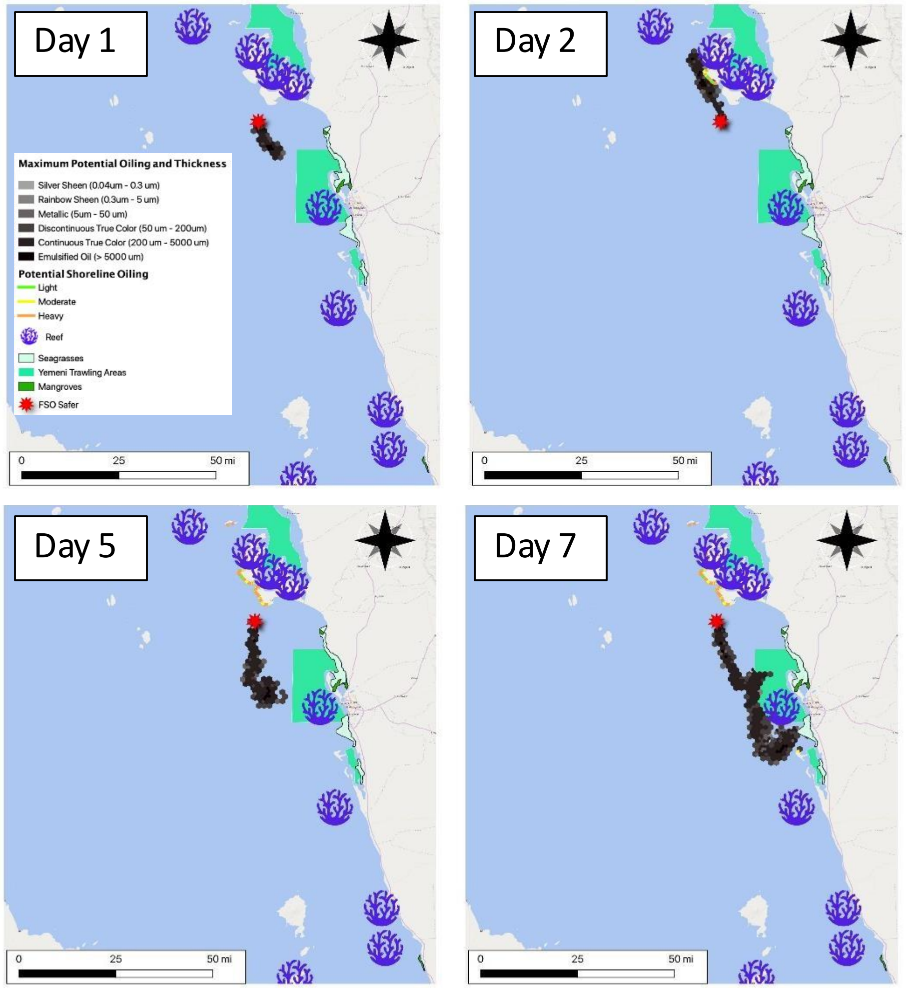
Region 2: 57 miles of potential shoreline oiling. Including At Tarfah and Jazirat at Tarfah islands. Mainland coastal Yemen from Al Hudaydah south to Al Khawkhah is forecasted to be impacted by shoreline oiling.

Coral-derived sand is the predominant shoreline material for the islands that are potentially impacted in the oil spill simulation (Region 1). Region 2 shoreline is also predominantly sand (90%) but 10% of the shoreline in this region is vegetated, including critical mangrove habitat.

Immediate removal of contaminated material would be required to prevent migration of stranded oil deeper into the sand matrix. Excavation and high-pressure washing systems are the primary clean-up tools used on this type of oiled shoreline. The potentially impacted mangroves are more difficult to remediate. In this type of ecosystem, oil retention has been documented to exceed decadal timescales.



Summer Oil Plume Evolution: Week 1



Summary of Location and Potential Impacts

Day 1

- **Trajectory:** Transport to the SSE; oil plume extends roughly 11 miles
- **Reefs:** No reef impacts forecasted
- **Fisheries:** Plume 4 miles west of the major Al Hudaydah Fishing Region
- **Shoreline:** No predicted shoreline oiling

Day 2: Tides and Winds Change, Causing Transport to the North

- **Trajectory:** Transport to the NNW; oil plume extends 20 miles
- **Reefs:** Kamaran Reef
- **Fisheries:** Kamaran Fishing Region impacted
- **Shoreline:** 5 miles of shoreline on Kamaran Island impacted

Day 5: Tides and Winds Change, Causing a Shift to the South

- **Trajectory:** Winds and currents shift, resulting in transport to the south. The oil plume is forecasted to extend 23 miles south from the release location.
- **Reefs:** No new major reefs forecasted to be impacted by oil
- **Fisheries:** Western reaches of the Al Hudaydah Fishing Region impacted
- **Shoreline:** 20.4 miles of shoreline impacted, including Al Bawdi Island

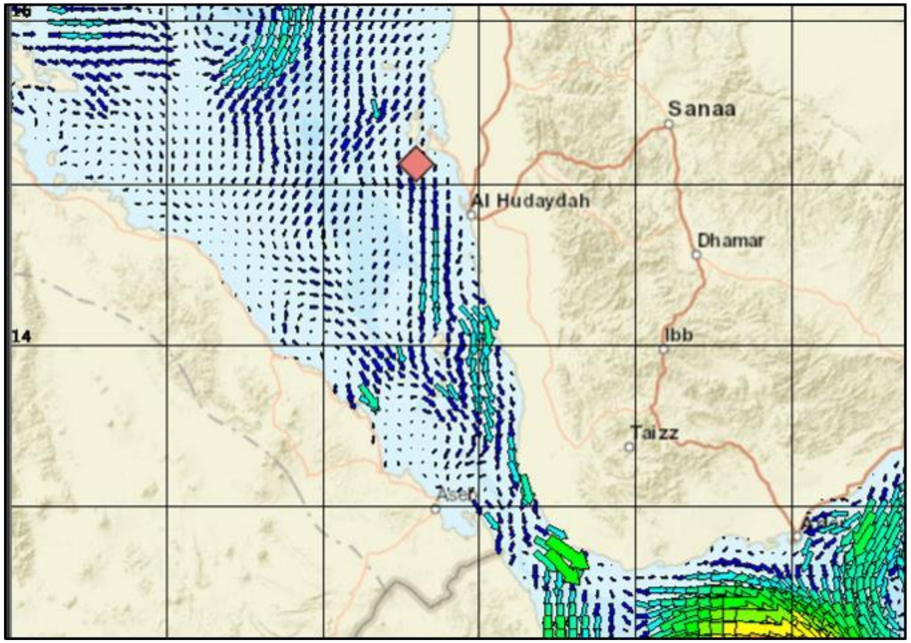
Day 7

- **Trajectory:** Transport to the southeast, oil plume roughly 41 miles long
- **Reefs:** Reefs around Al Hudaydah potentially impacted
- **Fisheries:** Additional impacts in the Al Hudaydah Fishing Region
- **Shoreline :** 22.2 miles of shoreline impacted, including At Tarfah Island.

Four Week Simulation: Summer

- A 50-million-gallon hypothetical release of crude oil into the Red Sea from the vessel was modeled during summer conditions
- The Marib-type crude oil on the vessel is considered a light crude oil. For this simulation, a medium crude oil with a lower aromatic fraction was used to simulate the loss of lighter material from oil aging.
- A constant release rate over a 14-day period was implemented for the simulation.
- Historical wind and hydrodynamic forecast information from July and August were used to represent typical summer weather conditions.
- Simulation start times were varied to incorporate environmental variability
- The deterministic forecast covers a single 4-week period.

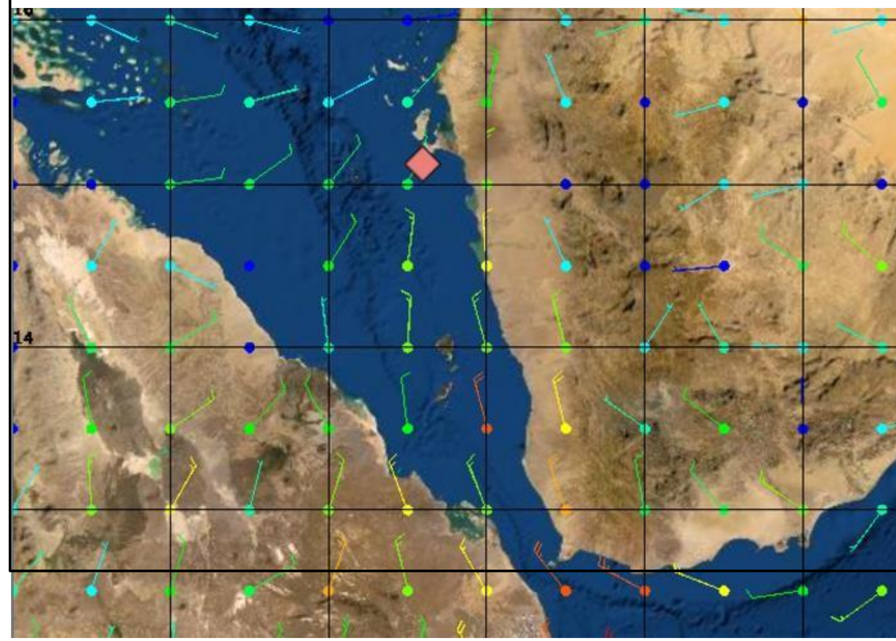
Model Forcing Data Summary: Summer



HYCOM currents for the Horn of Africa region were used for the hydrodynamic forcing.

Resolution: 0.08 degree, 3 hours (above).

Currents at the release site are persistent to the south/southeast. Convergence and some tidal shifting with much lower magnitude currents are observed 50-75 miles south of the release location, with weak currents to the north at the southernmost edge of the projected oil plume.



GFS forecast winds were used for the meteorological forcing of the oil spill simulation.

Resolution: 0.5 degree, 3 hours (above).

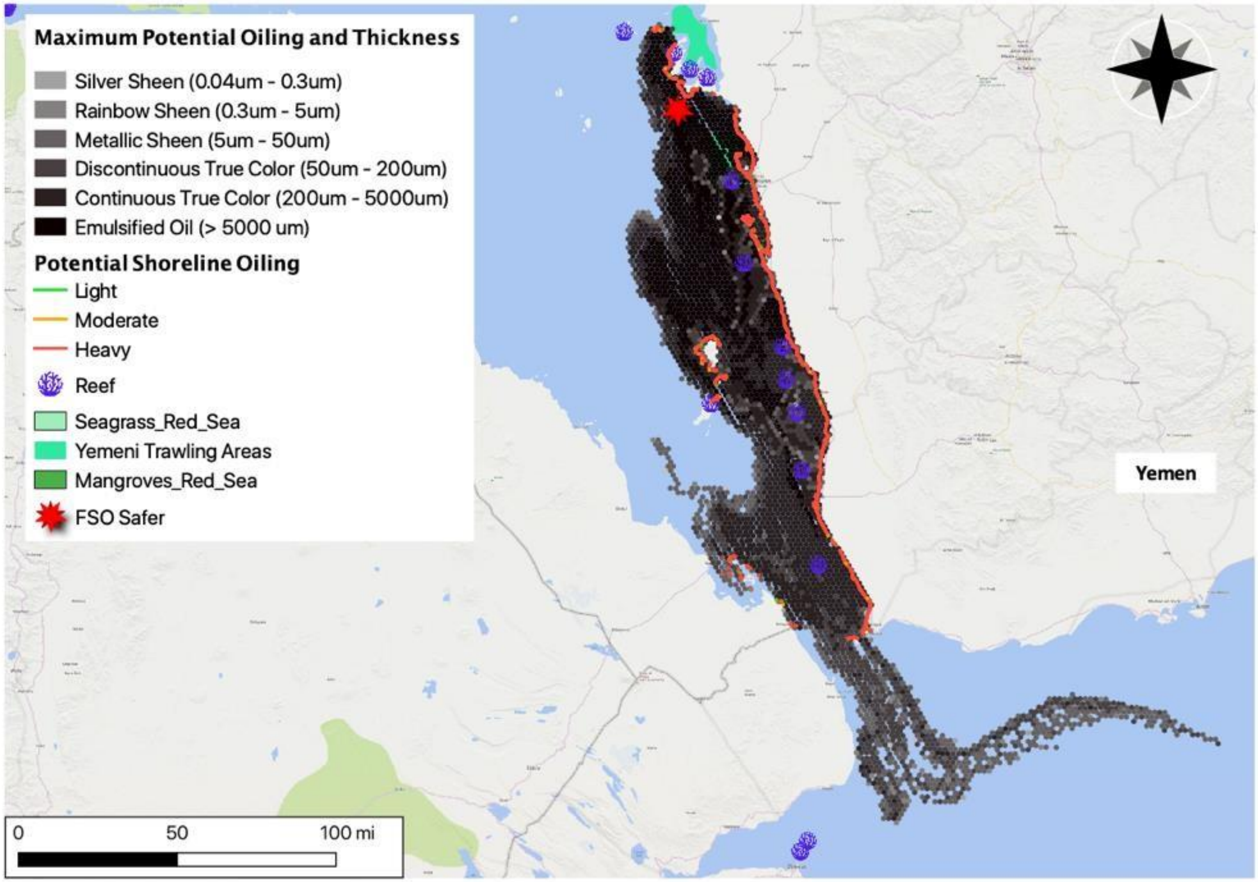
Persistent 15-18 knot northerly winds were forecasted during the first 24 hours of the simulation, driving the oil plume to the south. Between days 2-3, the wind field weakened, becoming variable and southerly. 10-16 knots winds from the north/northwest were forecasted across the plume for the remainder of the simulation.

Waterborne Summary: Summer; 4 Week Simulation

- The total forecast covers 28 days after the initial release started.
- The overall material transport extends approximately 267 miles from the current location of the FSO Safer to the southeast and 13 miles to the north.
- The released material impacts an area of approximately 8150 square miles over the course of the 28-day simulation.
- Shoreline material stranding and retention significantly impact the coast of Yemen. Approximately 57% of the material is retained at the shoreline, while 42% of the material is predicted to evaporate, and less than 1% remains in the water after 28 days.
- 267 miles of shoreline are potentially impacted by the released oil.
- Eleven major reefs are potentially impacted by oil.
- Three major fishing grounds are potentially impacted by oil.

Waterborne Hazard Forecast Summary: Summer

Total area covered and maximum thickness over the course of the <u>entire</u> simulation.



The oil travels approximately 240 miles to the southeast and 40 miles to the north over the 28-day simulation.

8150 mi^2 of water surface is potentially impacted by oil.

Heavy and moderate potential surface oiling is observed during the entire simulation.

Approximately 267 miles of shoreline would potentially be impacted by stranded oil.

11 major reefs are potentially subject to direct oiling.

3 of the major Yemeni Trawling Areas in the Red Sea are potentially impacted (367 square miles).

Potential Fisheries Impact Summary: Summer

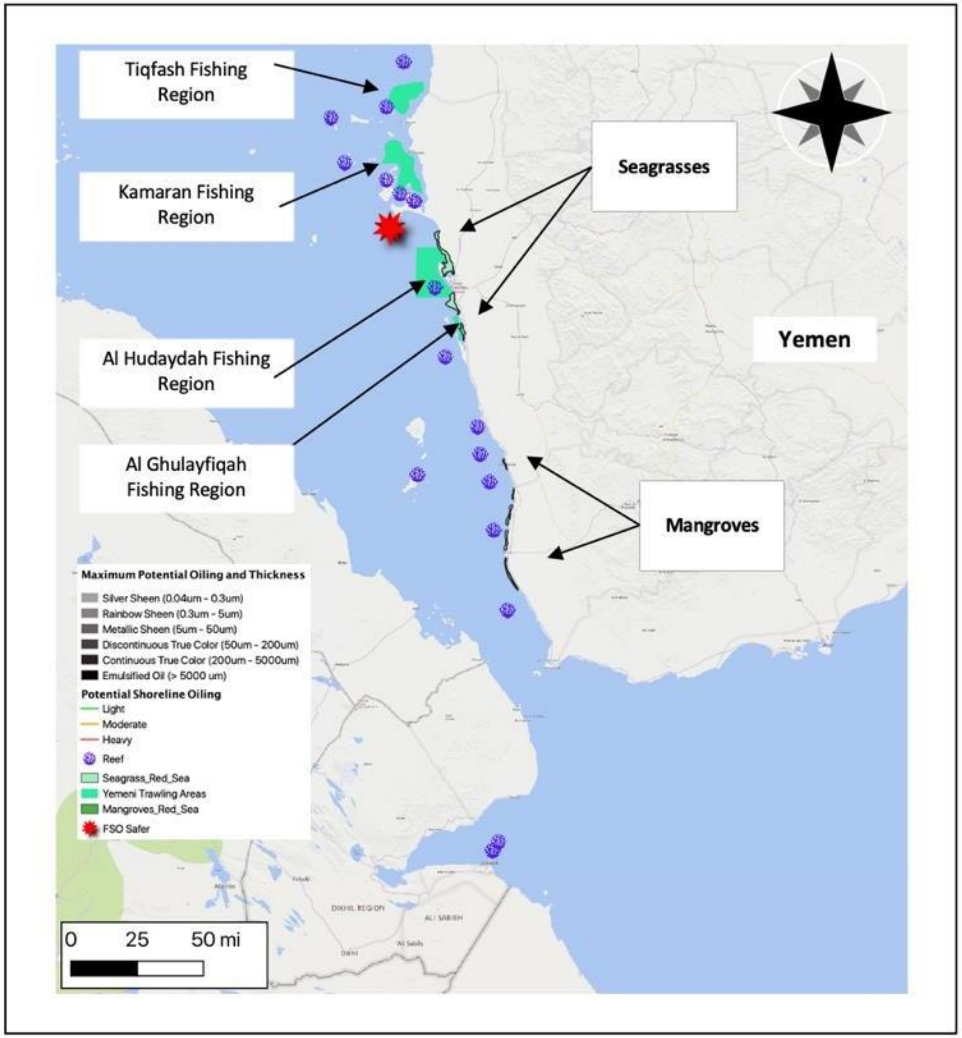
Within 28 days, up to 367 mi^2 of Yemen's major trawling grounds in the Red Sea could be impacted by oil. Impacts in the Kamaran Fishing Region are forecasted within two days of the hypothetical oil spill. Major fishing grounds around Al Hudaydah are potentially impacted by the end of the first week. Within 10 days, the major fisheries around Al Ghulayfiqah are also forecasted to be impacted under typical summer wind and current conditions.

These three regions represent >75% of the major trawling grounds along the Yemeni Red Sea coast, which in total accounts for 10% of Yemen's total fish production.

Types of Fisheries:

- Trawling & Gillnet
- Important Commercial Species in the Red Sea:
  - Penaeid shrimp, cuttlefish, rock lobster, Indian mackerel, Spanish mackerel, yellowfin tuna, snapper, jackfish, lizard-fish, grouper, rabbitfish, sea-bream, sharks.

Coastal mangroves provide vital fish nursery habitat and help to maintain the water clarity needed for active healthy reef ecosystems. Oiling of these sensitive regions can disrupt local fisheries, with full recovery times on the order of decades.



Potential Reef Impact Summary: Summer

The Red Sea has some of the highest diversity of coral reefs in the world with over 300 species of coral. There are more than 220 species in the region forecasted to be impacted by oil under the prevailing weather and current conditions.

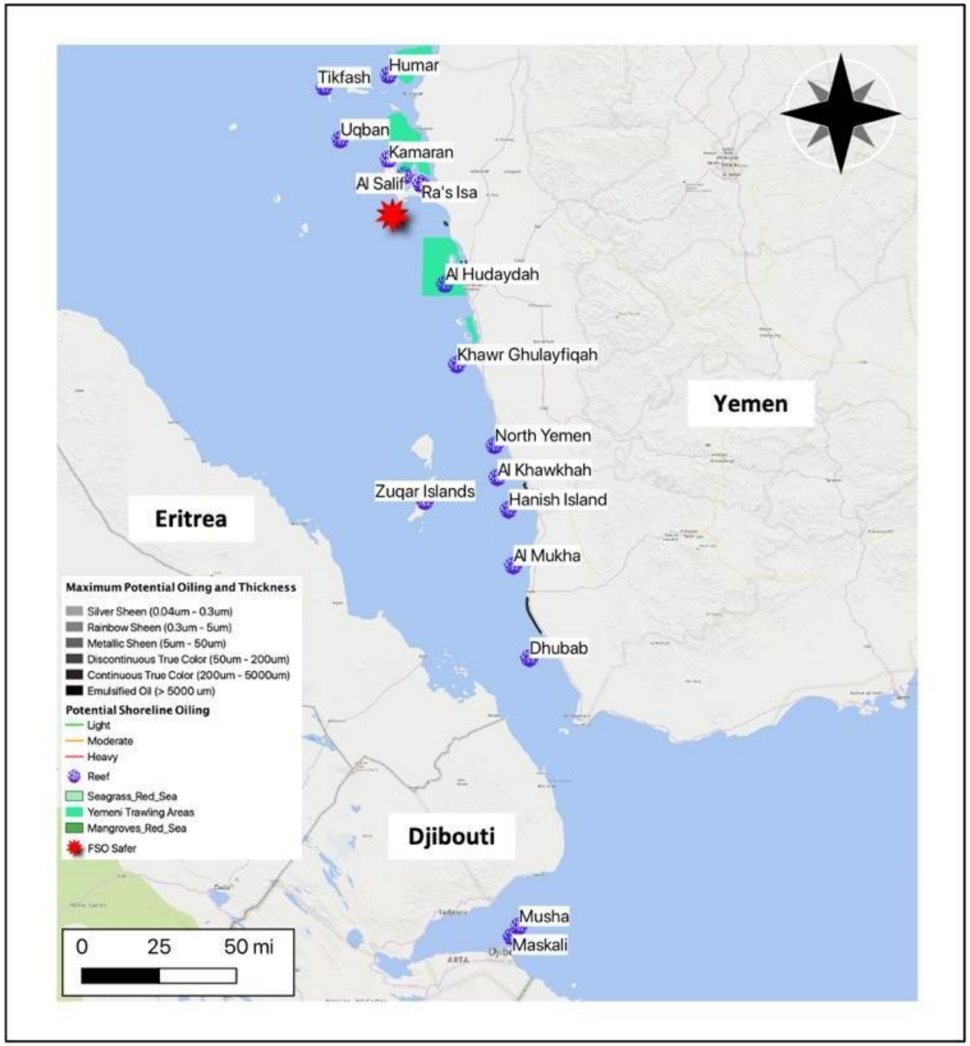
Types of Reefs

Major reef types in the Southern Red Sea in the potentially impacted area:

- Fringing reefs, the most common type of reef which grow near coastlines.
- Ring reefs, rings of coral that create protected lagoons.
- Pillar reefs: Primarily composed of the threatened pillar coral species.

Potential Immediate Impacts

- Within a 28-day period, 11 major coral reefs are potentially impacted by oil.
- Dispersed or emulsified oil could smother coral, sponges, crustaceans, and mollusks, particularly in the shallow fringing reef systems common to the region.
- Floating oil reduces water clarity, impeding photosynthesis. Floating oil can also adversely impact the microorganisms that serve as the foundation of the marine food web, reducing food availability to fish and marine organisms.



Resources Potentially Impacted: Summer

MAJOR REEFS			
Name	**Country**	**Type**	**Impact**
Kamaran	Yemen	Fringing	Fringing systems are found in shallow waters, providing conditions to support seagrasses. These areas are important for fisheries nurseries. Non-reef coral communities provide additional critical habitat for fish and other commercially important sea-life. There is moderate to high density coral diversity (221 species) along the Yemeni Coast, with diversity towards the south.
Al Salif	Yemen	Fringing	
Ra's isa	Yemen	Fringing	
Al Hudaydah	Yemen	Non-reef coral community	
Khawr Ghulayfiqah	Yemen	Non-reef coral community	
North Yemen	Yemen	Fringing/Patch/Non-reef coral community	
Al Khawkhah	Yemen	Non-reef coral community	
Zugar islands	Yemen	Fringing	
Hanish island	Yemen	Fringing	
Al Mukha	Yemen	Fringing	
Dhubab	Yemen	Fringing	
FISHERIES			
Trawling Grounds	Yemen	----	The Red Sea accounts for >10% of Yemen's fisheries production. Artisanal fishing is the primary source of income for the coastal community along the Red Sea. There are an estimated 850K tons of fisheries stocks along the Yemeni Red Sea Coast. Major species: Cuttlefish, Shrimp, Rock Lobsters, Sardines, Mackerel, Shark
DESALINATION PLANTS			
There are no functional desalination plants in the potential region of oil impact.			
POWER PLANTS			
There are no identified power plants in the potential region of impact.			

Potential Shoreline Impact Summary: Summer

Approximately 267 miles of shoreline are predicted to be impacted by oil over the course of the 14-day simulation. Potential shoreline oiling is anticipated in 3 regions:

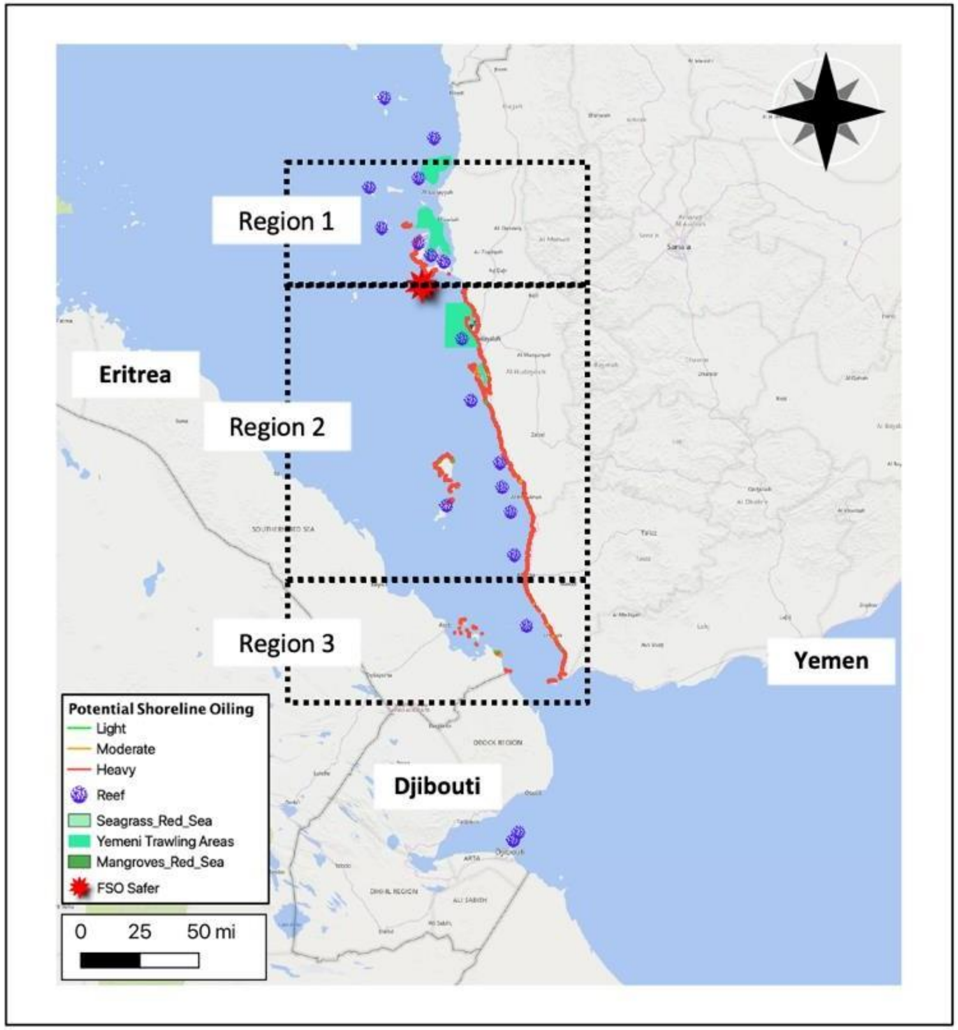
Region 1: 32 miles of potential shoreline oiling north of the FSO Safer. Includes key Yemeni fisheries, reefs, and Kamaran and Al Bawdi Islands.

Region 2: 225 miles of potential shoreline oiling south of the FSO Safer to Mokha, Yemen is forecasted to be impacted by shoreline oiling.

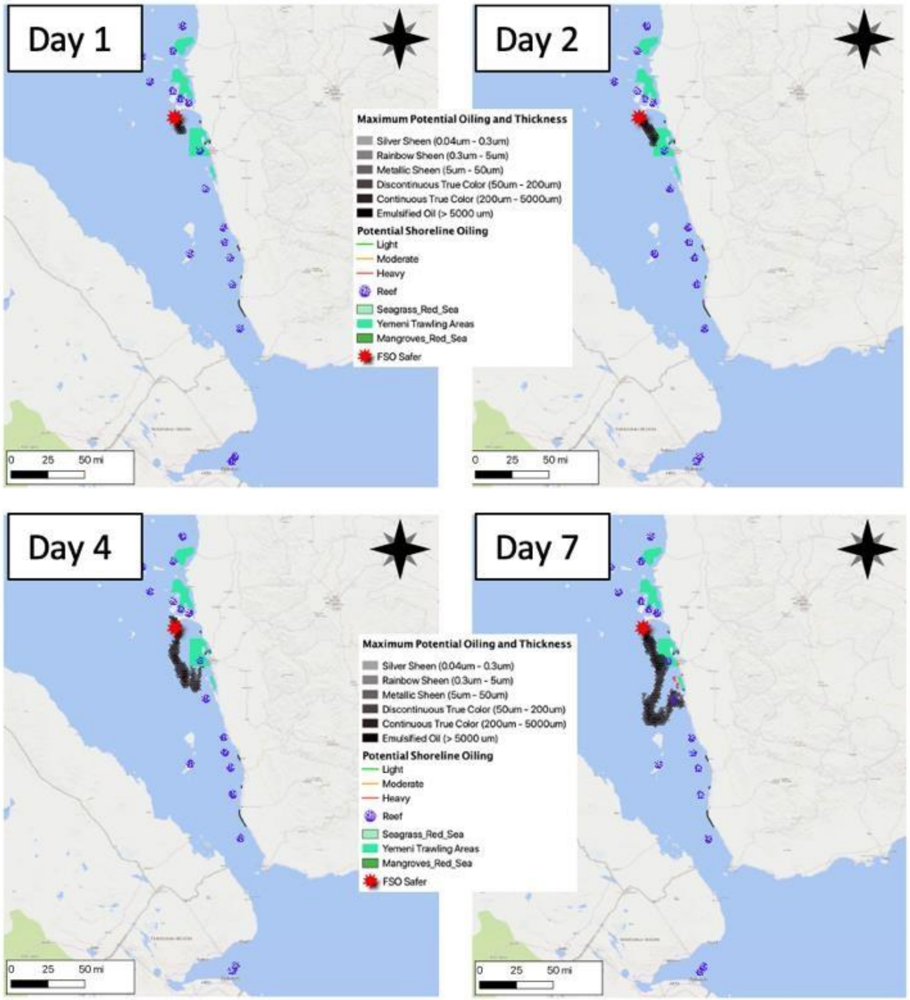
Region 3: 10 miles of potential shoreline oiling, south of Mokha, Yemen to the Al-Mandeb Straits and west to Eritrea are forecasted to be impacted by shoreline oiling.

Coral-derived sand is the predominant shoreline material for the islands that are potentially impacted in the oil spill simulation, but 10% of the shoreline in this region is vegetated, including critical mangrove habitat.

Immediate removal of contaminated material would be required to prevent migration of stranded oil deeper into the sand matrix. Excavation and high-pressure washing systems are the primary clean-up tools used on this type of oiled shoreline. The potentially impacted mangroves are more difficult to remediate. In this type of ecosystem, oil retention has been documented to exceed decadal timescales.



Summer Oil Plume Evolution: Week 1



Summary of Location and Potential Impacts

Day 1

- **Trajectory:** Transport to the SSE; oil plume extends roughly 13.4 miles
- **Reefs:** No reef impacts forecasted
- **Fisheries:** Plume 6 miles west of the major Al Hudaydah Fishing Region
- **Shoreline:** No predicted shoreline oiling

Day 2: Tides and Winds Change, Causing Transport to the North

- **Trajectory:** Transport to the SSE; oil plume extends 23 miles
- **Reefs:** No reef impacts forecasted
- **Fisheries:** Al Hudaydah Region impacted
- **Shoreline:** No predicted shoreline oiling

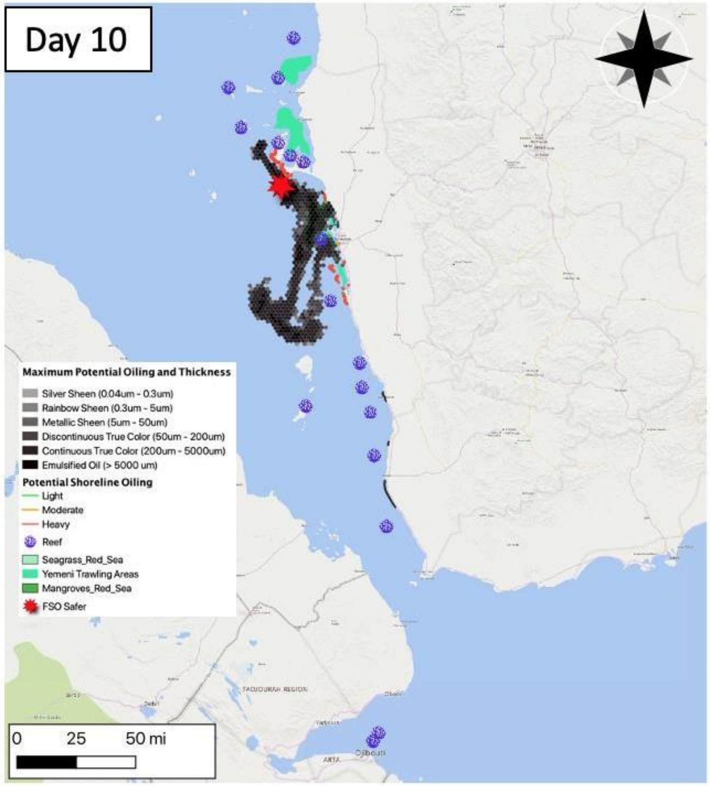
Day 4: Tides and Winds Change, Causing a Shift to the North

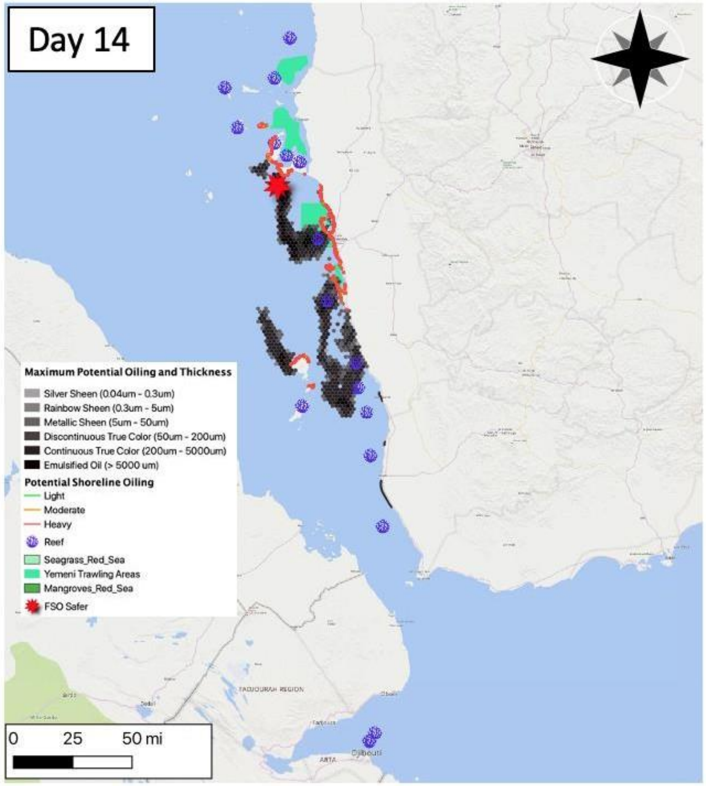
- **Trajectory:** Winds and currents shift, resulting in transport to the north. The oil plume is forecasted to extend48 miles south from the release location and 8 miles to the north.
- **Reefs:** Reefs around Al Hudaydah potentially impacted
- **Fisheries:** Western reaches of the Al Hudaydah Fishing Region impacted
- **Shoreline:** No predicted shoreline oiling

Day 7

- **Trajectory:** Transport to the southeast, oil plume roughly 78 miles long
- **Reefs:** Khawr Ghulayfiqah potentially impacted by oil
- **Fisheries:** Additional impacts in the Al Hudaydah Fishing Region
- **Shoreline :** 1 mile of shoreline potentially impacted by heavy oiling.

Summer Oil Plume Evolution: Week 2





Summary of Location and Potential Impacts

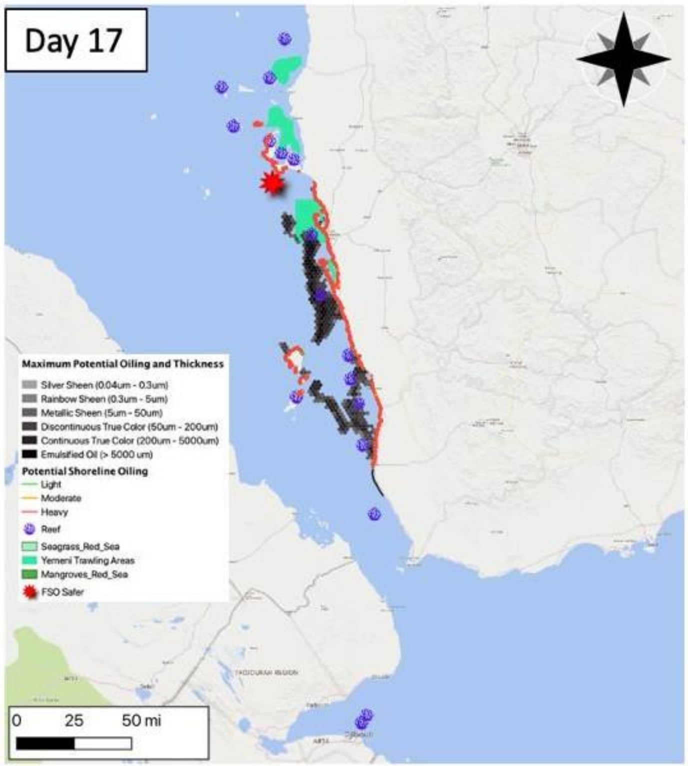
Day 10

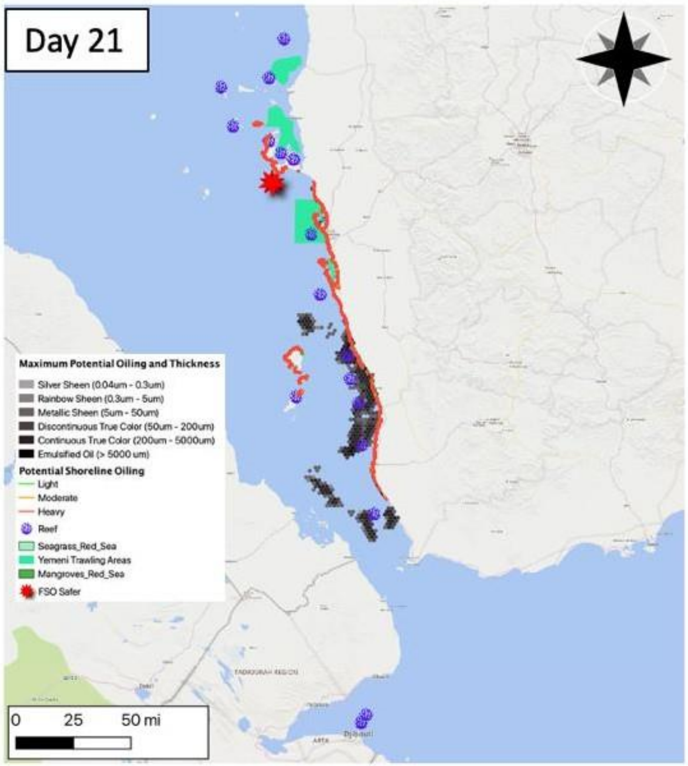
- **Trajectory:** Transport to the SSE; leading edge of the plume is 70 miles SSE
- **Reefs:** No new reef impacts
- **Fisheries:** Al Ghulayfiqah Fishing Region potentially impacted.
- **Shoreline:** 16 miles of shoreline; heavy oiling predicted for coastal Yemen south to Al Ghulayfiqah

Day 14

- **Trajectory:** Transport to the SSE; leading edge of the plume 105 miles SSE
- **Reefs:** North Yemen reef
- **Fisheries:** No new fishing regions impacted
- **Shoreline:** 100 miles of shoreline potentially impact south to Al Khawkhah

Summer Oil Plume Evolution: Week 3





Summary of Location and Potential Impacts

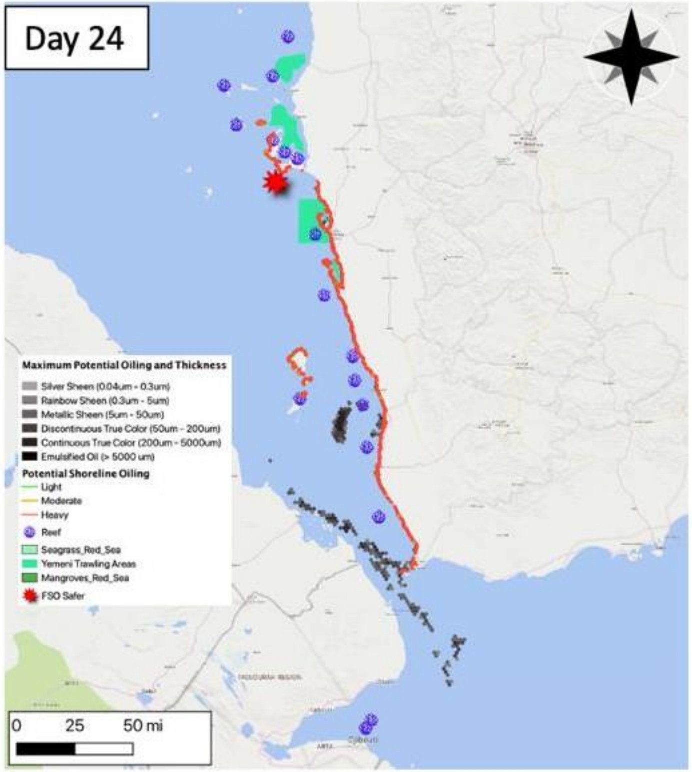
Day 17

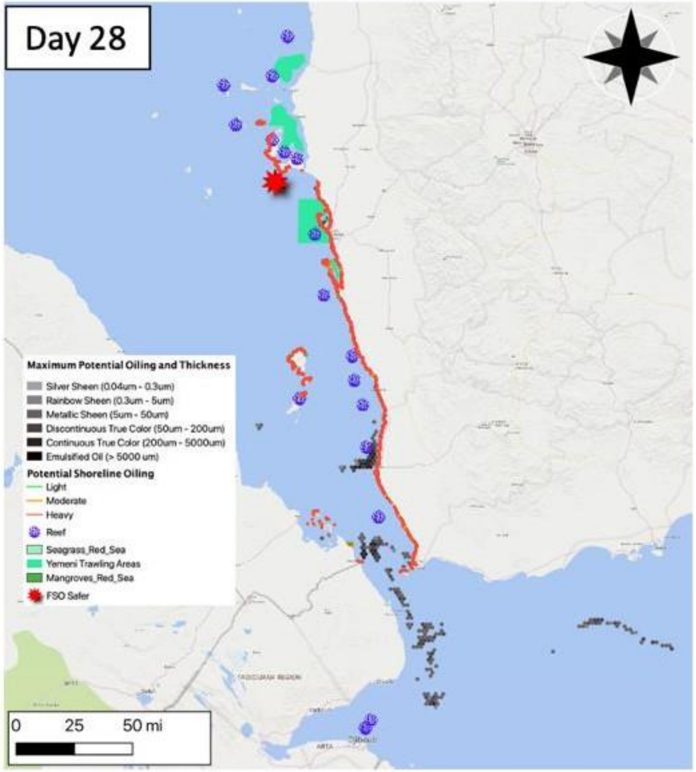
- **Trajectory:** Transport to the SSE; leading edge of the plume is 130 miles SSE
- **Reefs:** Zugar Islands, Al Khawhah, Hanish islands, Al Mukha
- **Fisheries:** No new fishing regions impacted
- **Shoreline:** 175 miles of shoreline; heavy oiling predicted for coastal Yemen from south to Mokha.

Day 21

- **Trajectory:** Transport to the SSE; leading edge of the plume 164 miles SSE
- **Reefs:** Dhubab
- **Fisheries:** No new fishing regions impacted
- **Shoreline:** 220 miles of shoreline; oiling predicted south to Al Khawkhah

Summer Oil Plume Evolution: Week 4





Summary of Location and Potential Impacts

Day 24

- **Trajectory: L**eading edge of the plume is 231 miles SSE through the Bab Al-Mandeb Strait
- **Reefs:** no new reefs impacted
- **Fisheries:** No new fishing regions impacted
- **Shoreline:** 260 miles of shoreline; heavy oiling predicted for coastal Yemen from and islands

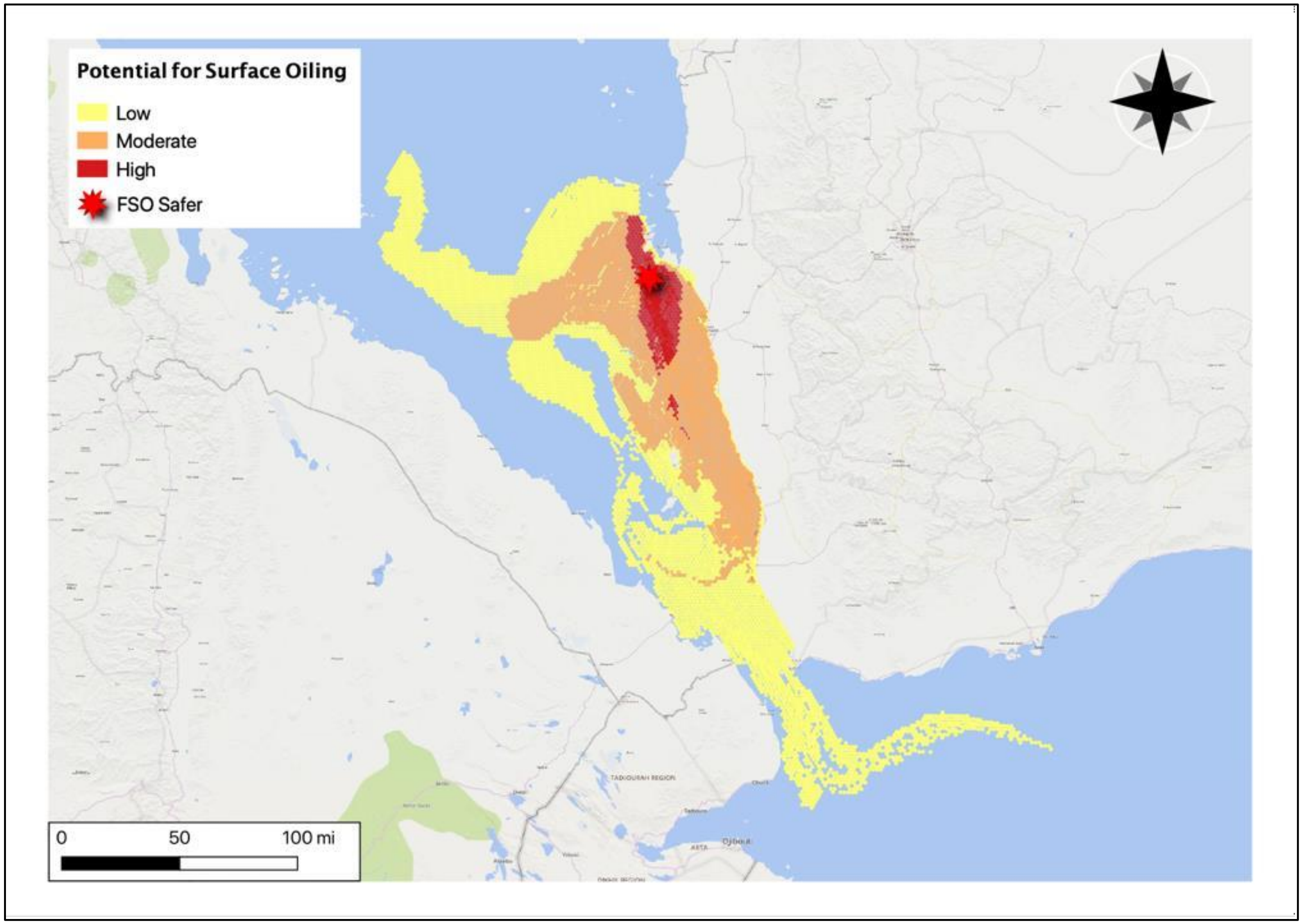
Day 28

- **Trajectory:** Oil is forecasted to be largely dispersed, with small pockets of oil 265 miles to the south in the Gulf of Aden
- **Reefs:** no new reefs impacted
- **Fisheries:** No new fishing regions impacted
- **Shoreline:** 267 miles of shoreline; oiling predicted west to Eritrea

Stochastic Simulation

- The FSO Safer is a growing environmental concern due to the large amount of oil on the vessel.
- A 50-million-gallon hypothetical release of crude oil into the Red Sea from the vessel was modeled during summer conditions
- The Marib-type crude oil on the vessel is considered a light crude oil. For this simulation, a medium crude oil with a lower aromatic fraction was used to simulate the loss of lighter material from oil aging.
- A constant release rate over a 14-day period was implemented.
- Historical wind and hydrodynamic forecast information from July and August were used to represent typical summer weather conditions.
- **Simulation start times were varied to incorporate environmental variability. Model start times were varied to develop a probabilistic map of surface oiling for summer conditions. A total of seven simulations were run (original deterministic plus six variations).**

Surface Oiling Potential: Summer



To investigate variability in the potential surface oiling footprint, six additional waterborne hazard forecasting simulations were conducted. Simulation start times were varied in 1 week increments to capture the impact of variations in the meteorological and hydrodynamic forecast data on the surface oiling and material transport.

The source terms assumed a catastrophic release of 50 million gallons at a constant release rate for two weeks. Each simulation was run for 4 weeks.

Surface oiling potential was calculated from the number of simulations where surface oiling was observed at all locations that impacted in the simulations.

Persistent westerly winds and hydrodynamic transport to the south keep the highest potential surface oiling areas to the southeast of the FSO Safer. Further afield, surface oiling is less likely and when observed, is highly dispersed.