2 THE ENVIRONMENTAL SENSITIVITY INDEX MAPPING SYSTEM

ESI maps are comprised of three general types of information:

1. Shoreline Classification–ranked according to a scale relating to sensitivity, natural persistence of oil, and ease of cleanup.

2. Biological Resources–including oil-sensitive animals and rare plants; and habitats, which are used by oil-sensitive species or are themselves sensitive to oil spills, such as submersed aquatic vegetation and coral reefs.

3. Human-Use Resources–specific areas that have added sensitivity and value because of their use, such as beaches, parks and marine sanctuaries, water intakes, and archaeological sites.

Each of these elements is discussed in the following sections.

Shoreline Classification

Shoreline habitats are at risk during spills because of the high likelihood of being directly oiled when floating slicks impact the shoreline. Oil fate and effects vary significantly by shoreline type, and many cleanup methods are shoreline-specific. The concept of mapping coastal environments and ranking them on a scale of relative sensitivity was originated in 1976 for Lower Cook Inlet (Michel et al. 1978). Since that time, the ranking system has been refined and expanded to cover shoreline types for most of North America, Central America, and portions of the Middle East. The ranking system is most developed for sub-arctic, temperate, and tropical zones. However, some shoreline types unique to the Arctic zone, such as peat scarps and eroding tundra scarps, are included in the ranking scheme. The classification scheme has also been modified to include lacustrine and riverine shoreline types (NOAA 1995). The complete list of standard ESI shoreline rankings is composed of categories for four environmental settings: estuarine, lacustrine, riverine, and palustrine (Table 2) To facilitate data use and exchange, these shoreline types and ranks should be used on all sensitivity mapping projects.

Table 2. ESI shoreline classification for the three types of environmental settings.

ESI NO.	ESTUARINE	LACUSTRINE	RIVERINE
1A	Exposed rocky shores	Exposed rocky shores	Exposed rocky banks
1B	Exposed, solid man-made structures	Exposed, solid man-made structures	Exposed, solid man-made structures
1C	Exposed rocky cliffs with boulder talus base	Exposed rocky cliffs with boulder talus base	Exposed rocky cliffs with boulder talus base
2A	Exposed wave-cut platforms in bedrock, mud, or clay	Shelving bedrock shores	Rocky shoals; bedrock ledges
2B	Exposed scarps and steep slopes in clay		
3A	Fine- to medium-grained sand beaches		
3B	Scarps and steep slopes in sand	Eroding scarps in unconsolidated sediments	Exposed, eroding banks in unconsolidated sediments
3C	Tundra cliffs		
4	Coarse-grained sand beaches	Sand beaches	Sandy bars and gently sloping banks
5	Mixed sand and gravel beaches	Mixed sand and gravel beaches	Mixed sand and gravel bars and gently sloping banks
6A	Gravel beaches Gravel Beaches (granules and pebbles)*	Gravel beaches	Gravel bars and gently sloping banks
6B	Riprap Gravel Beaches (cobbles and boulders)*	Riprap	Riprap
6C*	Riprap		
7	Exposed tidal flats	Exposed tidal flats	
8A	Sheltered scarps in bedrock, mud, or clay Sheltered rocky shores (impermeable)*	Sheltered scarps in bedrock, mud, or clay	
8B	Sheltered, solid man-made structures Sheltered rocky shores (permeable)*	Sheltered, solid man-made structures	Sheltered, solid man-made structures
8C	Sheltered riprap	Sheltered riprap	Sheltered riprap
8D	Sheltered rocky rubble shores		

Table 2. ESI shoreline classification, cont.

ESI NO.	ESTUARINE	LACUSTRINE	RIVERINE
8E	Peat shorelines		
8F			Vegetated, steeply-sloping bluffs
9A	Sheltered tidal flats	Sheltered sand/mud flats	
9B	Vegetated low banks	Vegetated low banks	Vegetated low banks
9C	Hypersaline tidal flats		
10A	Salt- and brackish-water marshes		
10B	Freshwater marshes	Freshwater marshes	Freshwater marshes
10C	Swamps	Swamps	Swamps
10D	Scrub-shrub wetlands; Mangroves†	Scrub-shrub wetlands	Scrub-shrub wetlands
10E	Inundated low-lying tundra		

* Denotes that a category or definition applies only in Southeast Alaska.
† In tropical climates 10D indicates areas of dominant mangrove vegetation

ESI NO.	PALUSTRINE**
10B	Freshwater marshes
10C	Swamps
10D	Scrub-shrub wetlands

**Palustrine environment ESI codes are assigned based on the National Wetland Inventory (NWI) habitat classification system.

The classification scheme is based on an understanding of the physical and biological character of the shoreline environment, not just the substrate type and grain size. Relationships among physical processes, substrate type, and associated biota produce specific geomorphic/ecologic shoreline types, sediment transport patterns, and predictable patterns in oil behavior and biological impact. The concepts relating natural factors to the relative sensitivity of coastline, mostly developed in the estuarine setting, were slightly modified for lakes and rivers. The sensitivity ranking is controlled by the following factors:

1. Relative exposure to wave and tidal energy
2. Shoreline slope
3. Substrate type (grain size, mobility, penetration and/or burial, and trafficability)
4. Biological productivity and sensitivity

All of these factors and first-hand observations from spills were considered when developing the relative ESI rankings for shoreline types. Each of the natural factors is discussed in detail below.

Relative Degree of Exposure to Wave and Tidal Energy

Biologists have long recognized that the makeup of intertidal biological communities is closely correlated with relative degree of exposure. In *Between Pacific Tides*, Rickets et al. (1968) classified the coastal habitats of the central California coast as *exposed* and *sheltered*, differentiating between settings subject to intense pounding by the large waves on that coast and those sheltered by offshore rocks, barrier beaches, and other protective features. Early geomorphology studies at the *Metula*, *Urquiola*, and *Amoco Cadiz* oil spills showed that the level of impacts of oil spills is closely related to the relative degree of exposure of the impacted habitat (Hayes and Gundlach 1975; Gundlach and Hayes 1978; Gundlach et al. 1978; Michel et al. 1978).

Two physical factors, wave-energy flux and tidal-energy flux, primarily determine the degree of exposure, also referred to as the *hydrodynamic energy level*, at the coastline. Wave-energy flux is basically a function of the average wave height, measured over at least one year. Where waves are typically large (e.g., heights more than one meter occur frequently), the impact of oil spills on the exposed habitats is reduced because:
1) offshore-directed currents generated by waves reflecting off hard surfaces push the oil away from the shore; 2) wave-generated currents mix and rework coastal sediments, which are typically coarse-grained in these settings, rapidly removing stranded oil; and 3) organisms adapted to living in such a setting are accustomed to short-term perturbations in the environment.

Tidal-energy flux is also important in determining the potential of oil-spill impacts on coastal habitats, although not as pervasive as wave-energy flux. The most important considerations are the potential for strong tidal currents to remove stranded oil and to build and move intertidal sand and/or gravel bars that bury oil. The effect of the currents on biological communities can also be pronounced. For example, highly mobile substrates set in motion by strong tidal currents typically harbor considerably fewer infauna than stable substrates. Tidal currents generally increase as tidal range increases.

Wave and tidal energy combine to produce a continuum of energy along a coastline. For the sake of portrayal on a map, this continuum must be broken into classes, clear-cut divisions of high, medium, or low energy. Within a mapping region, the degree of energy present on one shoreline segment is assessed relative to the overall energy levels in the region. High-energy shorelines (1A-2B) are regularly exposed to large waves or strong tidal currents during all seasons. They most commonly occur along the outermost coastline of a region or where dominant winds cause waves to strike the shoreline directly or by wave refraction. Medium-energy shorelines (3A-7) often have seasonal patterns in storm frequency and wave size. Low-energy shorelines (8A-10E) are sheltered from wave and tidal energy, except during unusual or infrequent events. As a general rule, high- and medium-energy shorelines should not be mapped adjacent to low-energy shorelines unless there is a significant change in shoreline orientation or there is some offshore obstruction to wave energy.

Inherent in these energy classes are inferences to the persistence of stranded oil. *High energy* means rapid natural removal, usually within days to weeks. *Low energy* means slow, natural removal, usually within years. *Medium energy* means that stranded oil will be removed when the next high-energy event occurs, which could be days or months after the spill. The removal of oil on a medium-energy coast is an event-driven process. Shorelines that do not have predictable, seasonal storms that generate waves of a significant size or from a particular direction are even more difficult to characterize. Along these shorelines, high-energy events usually happen more than once each year but their timing is generally unknown. A shoreline of this type has the potential for longer-than-usual oil persistence. This type of shoreline has storm berms with one to three years of vegetation growth and greater macroalgae coverage on the larger boulders in the intertidal zone than would be seen on a beach exposed to more frequent storms. Efforts should be made to differentiate beaches with irregular patterns in sediment mobility, particularly for gravel beaches.

Shoreline Slope

Shoreline slope is a measure of the steepness of the intertidal zone between maximum high and low tides. It can be characterized as steep (greater than 30 degrees), moderate (between 30 and 5 degrees), or flat (less than 5 degrees).

The importance of shoreline slope in exposed settings is its effect on wave reflection and breaking. Steep intertidal areas are usually subject to abrupt wave run-up and breaking, and even reflection in places, which enhances natural cleanup of the shoreline. Flat intertidal areas, on the other hand, promote dissipation of wave energy further offshore, which lets oil remain longer in the intertidal zone. Also, the broad intertidal areas typically have more extensive areal biological communities (e.g., mussel beds, clam beds, and plant communities). In sheltered habitats, slope is a less important distinguishing factor with regard to oil-spill impacts, except that sensitive biological communities have more area to develop where the slopes are flatter.

Substrate Type

Substrate types are classified as:

- *Bedrock*, which can be further divided into impermeable and permeable, depending upon the presence of surficial deposits on top of the bedrock

- *Sediments*, which are divided by grain size as:
  - Mud, consisting of silt and clay, less than 0.06 millimeters (mm)
  - Fine- to medium-grained sand, ranging in size from 0.06-1 mm
  - Coarse-grained sand, ranging from 1-2 mm
  - Granule, ranging from 2-4 mm
  - Pebble, ranging from 4-64 mm
  - Cobble, ranging from 64-256 mm
  - Boulder, greater than 256 mm

- *Man-made materials,* such as:
  - Riprap, or broken rock of various sizes, usually cobble or larger, that are permeable to oil penetration
  - Seawalls that are composed of solid material, such as concrete or steel, which are impermeable to oil penetration

The most important substrate distinction is between bedrock and unconsolidated sediments. In unconsolidated sediments, there is the potential for penetration and/or burial of the oil. Penetration and burial are mechanically different but, when either or both occur in sedimentary substrates, they increase the persistence of oil, lead to potential long-term biological impacts, and make cleanup much more difficult and intrusive.

Penetration occurs when oil stranded on the surface sinks into permeable sediments; the depth of penetration is controlled by the grain size of the substrate, as well as the sorting (range of grain sizes in the sediments). Deepest penetration is expected for coarse sediments (gravel) that are most uniform in grain size (well-sorted). On gravel beaches, heavy oil accumulations can penetrate up to one meter. If the sediments are poorly sorted, such as on mixed-sand-and-gravel beaches, oil usually penetrates less than 50 centimeters (cm). Sand beaches are also differentiated into grain-size categories (fine- to medium-grained versus coarse-grained) that differ by permeability and thus potential depths of penetration. Muddy sediments have the lowest permeability and also tend to be water-saturated, so oil penetration is very limited. However, where infauna burrow into the substrate, burrows can provide a mechanism for oil to penetrate an otherwise impermeable substrate.

Burial occurs when clean sediments are deposited on top of oil layers. The rate of burial can vary widely and can be as short as six hours (one-half of a tidal cycle) after the initial stranding of oil. The most rapid burial usually occurs on coarse-grained sand beaches, because they have the highest mobility under normal wave and tidal conditions. Storms can mobilize gravel berms or bars, burying oil in gravel beaches. Along shorelines with strong seasonal storm patterns, there can be annual erosion/deposition cycles in the beach profile and sediment distribution patterns. These shorelines have the greatest potential for burial, particularly if the oil is stranded at the beginning of the depositional period.

Identifying man-made substrates is generally simple due to their often unnatural appearance from the air. Of the man-made shoreline types, riprap is the most important substrate to identify, in both sheltered and exposed energy regimes, due to response considerations and the potential for persistence of oil.

Substrate type also affects the trafficability, or ability for people and machinery to maneuver during a cleanup effort. In general, highly trafficable shorelines are ranked lower on the ESI scale than those on which cleanup crews will have difficulty moving or, more importantly, where they will cause additional damage in their cleanup effort. For example, fine-grained sand beaches are typically compacted and hard with little chance of workers trampling oil deep into the substrate. Therefore, they are generally the most trafficable of the sedimentary substrates. Coarse-grained beaches, on the other hand, tend to have moderate to steep slopes, are much less compacted, and have a high permeability, making walking difficult and more likely to drive any stranded oil deeper into the substrate. Gravel beaches are less trafficable still, due in part to multiple berms and cobbles and boulders. Vehicles tend to force oil into gravel beaches. Lastly, wetland habitats, because of their muddy substrate, have very low trafficabilty. Using equipment on muddy substrates is not possible because of the substrates' innate softness. Any traffic in a wetland habitat risks driving pooled oil deeper into the muddy substrate, affecting both the plants and burrowing fauna.

Biological Productivity and Sensitivity

The biological productivity of shoreline habitat is an integral component of the ESI ranking. Vegetated habitats, such as marshes and mangroves, have the highest ranking because of the potential for long-term impacts resulting from both exposure to oil and potential damages associated with cleanup activities in these kinds of habitats. Recovery of the ecological services can take decades in these most productive habitats. The ESI ranking reflects the general sensitivity of shoreline habitats. That is, all fine-grained sand beaches have an ESI = 3. Tidal flats are ranked high on the ESI scale because of their high benthic productivity and importance as feeding areas for fish and birds. The presence of other sensitive resources on a specific shoreline segment, such as turtle nesting on a fine-grained sand beach, does not affect the ESI ranking. The seasonal presence of other resources on a shoreline segment is addressed by mapping biological and human-use resources.

Definitions of ESI Rankings

Rank of 1: Exposed, Impermeable Vertical Substrates

The essential elements are:

- Regular exposure to high wave energy or tidal currents.
- Strong wave-reflection patterns are common.
- Substrate is impermeable (usually bedrock or cement) with no potential for subsurface penetration.
- Slope of the intertidal zone is 30 degrees or greater, resulting in a narrow intertidal zone.
- By the nature of the high-energy setting, attached organisms are hardy and accustomed to high hydraulic impacts and pressures.

Shoreline types that meet these elements include:

1A = Exposed rocky shores (estuarine, lacustrine, and riverine)

1B = Exposed, solid, man-made structures (estuarine, lacustrine, and riverine)

1C = Exposed rocky cliffs with boulder talus base

1C = Exposed, rocky cliffs/Boulder talus base

These shoreline types are exposed to large waves, which tend to keep oil offshore by reflecting waves. The substrate is impermeable so oil remains on the surface where natural processes will quickly remove any oil that does strand within a few weeks. Also, any stranded oil tends to form a band along the high-tide line or splash zone, above the elevation of the greatest biological value. No cleanup is generally required or recommended.

Rank of 2: Exposed, Impermeable Substrates, Non-Vertical

The essential elements are:

- Regular exposure to high wave energy or tidal currents.
- Regular strong wave-reflection patterns.
- Slope of the intertidal zone is usually less than 30 degrees, resulting in a wider intertidal zone; it can be less than five degrees and the intertidal zone can be up to hundreds of meters wide.
- Substrate is impermeable with no potential for subsurface penetration over much of the intertidal zone, although there can be a thin, mobile veneer of sediment in patches on the surface.
- Sediments can accumulate at the base of bedrock cliffs, but are regularly mobilized by storm waves.
- By the nature of the setting, attached organisms are hardy and used to high hydraulic impacts and pressures.

Shoreline types that meet these elements include:

2A = Exposed wave-cut platforms in bedrock, mud, or clay (estuarine)

2A = Shelving bedrock shores (lacustrine)

2A = Rocky shoals; bedrock ledges along rivers (riverine)

2B = Exposed scarps and steep slopes in clay (estuarine)

As with ESI = 1, these shorelines rank low because they are exposed to high wave energy. However, they have a flatter intertidal zone, sometimes with small accumulations of sediment at the high-tide line, where oil could persist for several weeks to months. When the sediments have been formed into a beach on the rocky platform that has~~with~~ multiple, wave-built berms, the maps designate the beach as a separate shoreline type. Along coastal plain areas, the equivalent shoreline type consists of scarps in relict marsh clay. Biological impacts can be immediate and severe, particularly if fresh oil slicks cover tidal pool communities on rocky platforms. However, the oil is usually removed quickly from the platform by wave action. Cleanup is not necessary except for removing oiled debris and oil deposits at the high-tide line, in areas of high recreational use, or to protect a nearshore resource, such as marine birds.

Rank of 3: Semi-Permeable Substrate, Low Potential for Oil Penetration and Burial; infauna present but not usually abundant

The essential elements are:

- The substrate is semi-permeable (fine- to medium-grained sand), with oil penetration usually less than ten cm.
- Sediments are well-sorted and compacted (hard).
- On beaches, the slope is very low, less than five degrees.
- The rate of sediment mobility is low, so the potential for rapid burial is low.
- Surface sediments are subject to regular reworking by waves and currents.
- There are relatively low densities of infauna.

Shoreline types that meet these elements include:

3A = Fine- to medium-grained sand beaches (estuarine)

3B = Scarps and steep slopes in sand (estuarine)

3B = Eroding scarps in unconsolidated sediments (lacustrine)

3B = Exposed, eroding river banks in unconsolidated sediments (riverine)

3C = Tundra cliffs (estuarine)

This shoreline rank includes exposed sand beaches on outer shores, sheltered sand beaches along bays and lagoons, and sandy scarps and banks along lake and river shores. Compact, fine-grained sand substrates inhibit oil penetration, minimizing the amount of oiled sediments to be removed. Furthermore, fine-grained sand beaches generally accrete slowly between storms, reducing the potential for burial of oil by clean sand. On sheltered sand beaches, burial is seldom of concern because of the low wave energy. On exposed beaches, oil may be buried deeply if the oil stranded right after an erosional storm or at the beginning of a seasonal accretionary period. Cleanup on fine-grained sand beaches is simplified by the hard substrate that can support vehicular and foot traffic. Infaunal densities vary significantly both spatially and temporally.

Rank of 4: Medium Permeability, Moderate Potential for Oil Penetration and Burial; infauna present but not usually abundant

The essential elements are:

- The substrate is permeable (coarse-grained sand), with oil penetration up to 25 cm possible.
- The slope is intermediate, between 5 and 15 degrees.
- Rate of sediment mobility is relatively high, with accumulation of up to 20 cm of sediments within a single tidal cycle possible; there is a potential for rapid burial and erosion of oil.
- Sediments are soft, with low trafficability.
- There are relatively low densities of infauna.

Shoreline types that meet these elements include:

4 = Coarse-grained sand beaches (estuarine)

4 = Sand beaches (lacustrine)

4 = Sandy bars and gently sloping banks (riverine)

Coarse-grained sand beaches are ranked separately and higher than fine- to medium-grained sand beaches because of the potential for higher oil penetration and burial, which can be as great as one meter. These beaches can undergo very rapid erosional and depositional cycles, with the potential for rapid burial of oil, even after only one tidal cycle. Cleanup is more difficult, as equipment tends to grind oil into the substrate because of the loosely packed sediment. Also, cleanup techniques have to deal with multiple layers of oiled and clean sediments, increasing the amount of sediments to be handled and disposed of. These more mobile sediments usually have low infaunal populations, which also vary greatly over time and space.In some areas, there is no clear distinction between beach types because they cannot be readily differentiated by grain size. Under these conditions, such as along the Great Lakes, all sand beaches are ranked as ESI = 4.

Rank of 5: Medium-to-High Permeability, High Potential for Oil Penetration and Burial; infauna present but not usually abundant

The essential elements are:

- Medium-to-high permeability of the substrate (mixed sand and gravel) allows oil penetration up to 50 cm.

- Spatial variations in the distribution of grain sizes are significant, with finer-grained sediments (sand to pebbles) at the high-tide line and coarser sediments (cobbles to boulders) in the storm berm and at the toe of the beach.
- The gravel component should comprise at least 20 percent of the sediments.
- The slope is intermediate, between eight and 15 degrees.
- Sediment mobility is very high only during storms, thus there is a potential for rapid burial and erosion of oil during storms.
- Sediments are soft, with low trafficability.
- Infauna and epifauna populations are low, except at the lowest intertidal levels.

Shoreline types that meet these elements include:

5 = Mixed sand and gravel beaches (estuarine and lacustrine)

5 = Mixed sand and gravel bars and gently sloping banks (riverine)

The gravel-sized component can be composed of bedrock, shell fragments, or coral rubble. Because of higher permeabilities, oil tends to penetrate deeply into sand and gravel beaches, making it difficult to remove contaminated sediment without causing erosion and sediment disposal problems. These beaches may undergo seasonal variations in wave energy and sediment reworking, so natural removal of deeply penetrated oil may only occur during storms that occur just once or twice per year. Biological use is low, because of high sediment mobility and rapid drying during low tide.

These types of beaches range widely in relative degree of exposure. Sediment mobility can be inferred by the extent of attached fauna and macroalgae. Indicator species or assemblage coverages can be used to reflect the potential rate of sediment reworking. For example, in southeastern Alaska, the presence of greater than 20 percent attached algae, mussels, and barnacles indicates beaches that are relatively sheltered, with the more stable substrate supporting a richer biota. Where there are significant differences in the degree of exposure of sand and gravel beaches, the more exposed or mobile beaches can be designated as 5A and the less exposed or stable beaches can be designated as 5B. Pocket beaches, in particular, can have microenvironments that are more protected from wave energy (called wave shadows) where natural removal may be much slower than the adjacent beach.

Rank of 6: High Permeability, High Potential for Oil Penetration and Burial

The essential elements are:

- The substrate is highly permeable (gravel-sized sediments), with penetration up to 100 cm.
- The slope is intermediate to steep, between ten and 20 degrees.
- Rapid burial and erosion of shallow oil can occur during storms.
- There is high annual variability in degree of exposure, and thus in the frequency of mobilization by waves.
- Penetration can extend to depths below those of annual reworking.
- Sediments have lowest trafficability of all beaches.
- Natural replenishment rate of sediments is the slowest of all beaches.
- Infauna and epifauna populations are low, except at the lowest intertidal levels.

Shoreline types that meet these elements include:

6A = Gravel beaches (estuarine and lacustrine)
6A = Gravel bars and gently sloping banks (riverine)
6A = Gravel beaches (cobbles and boulders) (estuarine - Southeast Alaska only)
6A = Gravel beaches (granules and pebbles) (estuarine – Southeast Alaska only)
6B = Riprap (estuarine, lacustrine, and riverine)
6B = Gravel beaches (cobbles and boulders) (estuarine – Southeast Alaska only)
6C = Riprap (estuarine - Southeast Alaska only)

Gravel beaches are ranked the highest of all beaches primarily because of the potential for very deep oil penetration and slow natural removal rates of subsurface oil. The slow replenishment rate of gravel makes removal of oiled sediment highly undesirable, and so cleanup of heavily oiled gravel beaches is particularly difficult. For many gravel beaches, significant wave action (meaning waves large enough to rework the sediments to the depth of oil penetration) occurs only every few years, leading to long-term persistence of subsurface oil. Shell fragments can be the equivalent of gravel along Gulf of Mexico and South Atlantic beaches.

Fine-grained gravel beaches are composed primarily of pebbles and cobbles (from 4 to 256 mm), with boulders as a minor fraction. Little sand is evident on the surface, and there is less than 20 percent sand in the subsurface. There can be zones of pure pebbles or cobbles, with the pebbles forming berms at the high-tide line and the cobbles and boulders dominating the lower beachface. Sediment mobility limits the amount of attached algae, barnacles, and mussels to low levels. The distinction can also be made on the basis of grain size and extent of rounding of the sediments on a shoreline. The gravel is rounded or well-rounded only on those beaches regularly mobilized during storms.

Large-grained gravel beaches have boulders dominating the lower intertidal zone. The amount of attached algae and epifauna is much higher, reflecting the stability of the large sediments. A boulder-and-cobble armoring of the surface of the middle to lower intertidal zone is common on these beaches. Armor may have a very important effect on oil persistence in gravel beaches. Oil beneath an armored surface would tend to remain longer than would subsurface oil on an unarmored beach with similar grain size and wave conditions because of the higher velocities required to mobilize the armor (NOAA 1993). Sub-rounded to sub-angular gravel is a very good indicator of these less mobile beaches.

Riprap is a man-made equivalent of this ESI rank, with added problems because it is usually placed at the high-tide line where the highest oil concentrations are found and the riprap boulders are sized so that they are not reworked by storm waves. Flushing can be effective for removing mobile oil, but large amounts of residue can remain after flushing, particularly for heavy oils. Sometimes, the only way to clean riprap completely is to remove and replace it.

Rank of 7: Exposed, Flat, Permeable Substrate; infauna usually abundant

The essential elements are:

- They are flat (less than three degrees) accumulations of sediment.
- The highly permeable substrate is dominated by sand, although there may be silt and gravel components.
- Sediments are water-saturated so oil penetration is very limited.
- Exposure to wave or tidal-current energy is evidenced by ripples in sand, scour marks around gravel, or presence of sand ridges or bars.
- Width can vary from a few meters to nearly one kilometer.
- Sediments are soft, with low trafficability.
- Infaunal densities are usually very high.

Shoreline types that meet these elements include:

7 = Exposed tidal flats (estuarine and lacustrine)

Exposed tidal flats commonly occur with other shoreline types, usually marsh vegetation, on the landward edge of the flat. Oil does not readily adhere to or penetrate the compact, water-saturated sediments of exposed sand flats. Instead, the oil is pushed across the surface and accumulates at the high-tide line. Even when large slicks spread over the tidal flat at low tide, the tidal currents associated with the next rising tide pick up the oil and move it alongshore. However, oil can penetrate the tops of sand bars and burrows if they dry out at low tide. Because of the high biological use, impacts can be significant to benthic invertebrates exposed to the water-accommodated fraction or smothered. Cleanup is always difficult because of the potential for mixing the oil deeper into the sediment, especially with foot traffic.

Rank of 8: Sheltered Impermeable Substrate, Hard; epibiota usually abundant

The essential elements are:

- They are sheltered from wave energy or strong tidal currents.
- Substrate is hard, composed of bedrock, man-made materials, or stiff clay.
- The type of bedrock can be highly variable, from smooth, vertical bedrock, to rubble slopes, which vary in permeability to oil.
- Slope is generally steep (greater than 15 degrees), resulting in a narrow intertidal zone.
- There is usually a very high coverage of attached algae and organisms.

Shoreline types that meet these elements include:

8A = Sheltered rocky shores and sheltered scarps in bedrock, mud, or clay (estuarine)

8A = Sheltered rocky shores (impermeable) and sheltered scarps in bedrock, mud, or clay (estuarine – Southeast Alaska only)

8A = Sheltered scarps in bedrock, mud, or clay (lacustrine)

8B = Sheltered, solid man-made structures, such as bulkheads (estuarine, lacustrine, and riverine)

8B = Sheltered rocky shores (permeable) (estuarine – Southeast Alaska only)

8C = Sheltered riprap (estuarine, lacustrine, and riverine)

8D = Sheltered rocky rubble shores (estuarine)

8E = Peat shorelines (estuarine)

8F = Vegetated, steeply-sloping bluffs (riverine)

Oil tends to coat rough rock surfaces in sheltered settings, and oil persists long-term because of the low-energy setting. Where appropriate, mapping should differentiate between solid rock surfaces, which are impermeable to oil, and rocky rubble slopes, which tend to trap oil beneath a veneer of coarse material. Both types can have large amounts of attached organisms, supporting a rich and diverse community. Cleanup is often required because natural removal rates are slow. Yet cleanup is often difficult and intrusive. Sheltered seawalls and riprap are the man-made equivalents, with similar oil behavior and persistence patterns. Usually, more intrusive cleanup is necessary for aesthetic reasons. In riverine settings, terrestrial vegetation along the river bluff indicates low energy and thus slow natural removal rates.

Rank of 9: Sheltered, Flat, Semi-Permeable Substrate, Soft; infauna usually abundant

The essential elements are:

- They are sheltered from exposure to wave energy or strong tidal currents.
- The substrate is flat (less than three degrees) and dominated by mud.
- The sediments are water-saturated, so permeability is very low, except where animal burrows are present.
- Width can vary from a few meters to nearly one kilometer.
- Sediments are soft, with low trafficability.
- Infaunal densities are usually very high.

Shoreline types that meet these elements include:

9A = Sheltered tidal flats (estuarine)
9A = Sheltered sand/mud flats (lacustrine)
9B = Vegetated low banks (estuarine and riverine)
9B = Sheltered, vegetated low banks (lacustrine)
9C = Hypersaline tidal flats (estuarine)

The soft substrate and limited access makes sheltered tidal flats almost impossible to clean. Usually, any cleanup efforts mix oil deeper into the sediments, prolonging recovery. Once oil reaches these habitats, natural removal rates are very slow. They can be important feeding areas for birds and rearing areas for fish, making them highly sensitive to oil-spill impacts. In areas without a significant tidal range, such as the Great Lakes, sheltered flats are created by less-frequent variations in water level. These flats are unique in that low-water conditions can persist for weeks to months, providing a mechanism for sediment contamination in areas that can be subsequently flooded. Low riverine banks are often muddy, soft, and vegetated, making them extremely difficult to clean. Natural removal rates could be very slow, and depend on flooding frequency.

Rank of 10: Vegetated Emergent Wetlands

The essential elements are:

- The substrate is flat and can vary from mud to sand, though high organic, muddy soils are most common.
- Various types of wetland vegetation, including herbaceous grasses and woody vegetation, cover the substrate. Floating aquatic vegetation (FAV) and submersed aquatic vegetation (SAV) are treated separately from the ESI classification as biological resources under the habitat/rare plant coverage.
- The break between salt- and brackish-water marshes and freshwater marshes occurs at the inland extent of 0.5 ppt salinity under average yearly low-flow conditions (Cowardin et al. 1979).
- The difference between scrub-shrub wetlands (<6 m) and swamps (=6 m) is plant height (Cowardin et al. 1979).

Shoreline types that meet these elements include:

10A = Salt- and brackish-water marshes (estuarine)

10B = Freshwater marshes (estuarine, lacustrine, riverine, and palustrine)

10C = Swamps (estuarine, lacustrine, riverine, and palustrine)

10D = Scrub-shrub wetlands (estuarine, lacustrine, riverine, and palustrine)

10D = Mangroves (in tropical climates) (estuarine)

10E = Inundated, low-lying tundra (estuarine)

Marshes, mangroves, and other vegetated wetlands are the most sensitive habitats because of their high biological use and value, difficulty of cleanup, and potential for long-term impacts to many organisms. When present, mangroves are considered a specific habitat type and are not grouped with scrub-shrub vegetation. Many factors influence how oil affects wetlands: oil type, extent of vegetation contamination, degree of sediment contamination, exposure to natural removal processes, time of year of the spill, and species types.

Biological Resources

Animals, plants, and habitats potentially at risk from oil spills are segmented into seven elements based on major taxonomic and functional groupings. Each element is further divided into groups of species or sub-elements with similar taxonomy, morphology, life history, and/or behavior relative to oil spill vulnerability and sensitivity (Table 3). For example, there are ten sub-elements for birds, including alcids, diving birds, gulls and terns, landfowl, passerine birds, pelagic birds, raptors, shorebirds, wading birds, and waterfowl.

Marine, coastal, and aquatic/wetland species may be present over a very large geographic area. Maps or data indicating the entire distribution of a large number of species potentially located in an area may not be very helpful to responders setting protection priorities. Therefore, it is important to identify the types of species that tend to be vulnerable to spilled oil, the most sensitive life-stages, and in which habitats these life-stages occur, as habitat type plays an important role in the persistence of oil and species exposure to oil.

Biological resources are most at risk from oil spills when:

- Large numbers of individuals are concentrated in a relatively small area;
- Marine or aquatic species come ashore during special life stages or activities, such as nesting, birthing, resting, or molting;
- Early life stages or important reproductive activities occur in sheltered, nearshore environments where oil tends to accumulate;
- Limited suitable habitat exists within an area for specific life stages or along critical migratory routes;
- Specific areas are known to be vital sources for seed or propagation;
- A species is threatened, endangered, or rare; or
- A significant percentage of the population is likely to be exposed to oil.

Therefore, the goal of mapping biological resources is to emphasize identifying locations and areas of the highest concentrations, and the most sensitive life-history stages and

Table 3. Biological resources included on sensitivity maps.

Data Element	Sub-Element	Areas/Sites to be Mapped
Marine Mammals	Dolphins	Concentration areas
	Manatees	Concentration areas, cold weather refugia
	Pinnipeds (Seals, Sea Lions, Walruses)	Haulouts, pupping sites, concentration areas
	Polar Bears	Concentration areas, denning concentrations
	Sea Otters	Concentration areas
	Whales	Migratory or other concentration areas
Terrestrial Mammals	Bats	Colonies for threatened and endangered species
	Bears	Intertidal feeding or aquatic/wetland concentrations, hazard areas for spill responders
	Canines	Threatened/endangered or rare species
	Felines	Threatened, endangered, or rare species
	Small Mammals	Aquatic fur-bearer concentrations, other special areas
	Ungulates	Migratory or other concentration areas
Birds	Alcids	Rookeries; wintering/rafting areas
	Diving Birds	Rookeries; forage/wintering areas; roosting concentrations
	Gulls and Terns	Nesting sites; other concentration areas
	Landfowl	Nesting sites and concentrations areas
	Passerine Birds	Threatened, endangered, or rare occurrences and nesting sites
	Pelagic Birds	Rookeries; roosting and rafting concentrations
	Raptors	Nesting sites; migratory/feeding concentrations
	Shorebirds	Nesting sites; migratory stopover concentrations
	Wading Birds	Rookeries; feeding and roosting concentrations
	Waterfowl	Migratory and wintering concentrations, nesting areas
Reptiles and Amphibians	Alligators/Crocodiles	Concentration areas, especially nesting
	Lizards, Snakes, Amphibians, and Other Reptiles	Threatened, endangered, or rare occurrences, especially aquatic/ wetland concentrations
	Turtles	Nesting and concentration areas
Fish	Anadromous Marine Resident Fish	Spawning, nursery, and other concentration areas

Table 3. Continued.

Data Element	**Sub-Element**	**Areas/Sites to be Mapped**
Fish	Diadromous Fish	Spawning runs, nursery areas, threatened, endangered, or rare occurrences
	Estuarine Nursery Fish	Spawning, nursery, and other concentration areas
	Estuarine Resident Fish	Spawning, nursery, and other concentration areas
	Freshwater Fish	Spawning and nursery areas; threatened, endangered, or rare occurrences
	Marine Benthic Fish	Spawning and nursery areas; concentrations in reefs, SAV, and other habitats
	Marine Pelagic Fish	Spawning, nursery, and other concentration areas
Invertebrates	Bivalves	Harvest areas; high concentrations; threatened, endangered, or rare occurrences
	Cephalopods	Harvest areas; high concentrations
	Crabs	Harvest and nursery areas; high concentrations
	Echinoderms	Harvest areas; high concentrations
	Gastropods	Harvest areas; high concentrations, threatened, endangered, or rare occurrences
	Insects	Threatened, endangered, or rare occurrences
	Lobsters and Crayfish	Nursery, spawning, and harvest areas; threatened, endangered, or rare occurrences
	Shrimp	Harvest and nursery areas; high concentrations
Habitats and Plants	Algae	Algal beds, important species
	Coral Reefs	Living, reef-building coral areas; rare species
	FAV	Floating aquatic vegetation
	Hardbottom Reefs	Other hard substrates that provide structural habitats or cover
	Kelp	Beds or forests of kelp
	SAV	Submersed aquatic vegetation
	Upland Plants	Special/rare upland (terrestrial) plants, habitats, or communities
Wetlands	Special/rare wetland plants, habitats, or	communities
	Worm Beds	Intertidal or subtidal beds of structure-building worm species

activities for certain species. The types of species that are typically mapped are those that are vulnerable and sensitive to oil spills and disturbance-related response activities; species that are threatened, endangered, or rare; and species that are of commercial/recreational importance (Table 3). In general, coastal, marine, aquatic, wetland, and riparian species and habitats are emphasized. In some cases, the sensitivity of a habitat type may be low, but the sensitivity of species that use or rely on the habitat may be high.

In addition to the geographic or spatial data depicted for biological resources, important attribute data are also included. Attribute data include: species names (common and scientific); the legal status of each species (state and/or federal threatened, endangered, and special concern listings); concentration/abundance; seasonal presence by month; and special life-history time-periods (e.g. spawning, nesting). In addition to federal and state legal status, the global conservation status ranks for certain species, as defined by The Nature Conservancy and the Natural Heritage Programs, are included in atlases published since 1997.

The concentration of a species in a given location may include qualitatively or quantitatively defined descriptions of species abundance (e.g., high, medium, or low), or numbers indicating the number of individuals, nesting or breeding pairs, or nests which occur at a site or within a polygon. The data collection tables, atlas introductory pages, and metadata identify the types of numbers included in the concentration field. When concentration is not known, the concentration field is left blank.

The monthly seasonality data contain “Xs” or abundance values in months when the species are present in the site or polygon location. The “Xs” indicate presence, while the numbers correspond to abundance categories. Monthly abundance is only used for fish and invertebrates data based on NOAA’s Estuarine Living Marine Resources (ELMR) databases. The numbers listed for each month in which the species is present correspond to: 1 = no information; 2 = rare; 3 = common; 4 = abundant; and 5 = highly abundant. In cases where ELMR fisheries data are used, the months in which high salinity (low rainfall, stream flow, or runoff), transitional, and low-salinity time-periods occur are indicated directly under the listing of the fish and invertebrates seasonalities as: H = high, T = transitional, and L = low.

Associated with each species location and monthly presence are the time-periods when various life-history stages or activities occur. The life-history time periods are different for each biological element. The life-history time periods listed are those that have resulted in the concentration of the species at the particular location (e.g., a nesting colony, spawning site, or nursery area has been mapped) and often are related to sensitive time-periods associated with reproductive activities or early life-history stages.

Finally, the databases include source documentation at the feature/species level. That is, for every species associated with each feature (a site or location indicated by a point, line, polygon, etc.) there can be a unique source or sources. Two source fields are used for biological resources, a geographic and a seasonality source. Typically, one source will provide the geographic location, species name or list, concentration, and type of resource occurrence (nesting site, migratory stop-over), while another source will be used to determine seasonality and life-history information. The same source may provide all of the information and would be listed as both the geographic and seasonality source.

Human-Use Resources

Human-use resources can be divided into four major components (Table 4):

- High-use recreational and shoreline access locations;
- Management areas;
- Resource extraction locations; and
- Archaeological and historical cultural resource locations.

Each of these components is discussed below.

Recreational Areas/Access Locations

Recreational areas shown on sensitivity maps include high-use recreational beaches, sport-fishing, diving sites, surfing areas, and artificial reefs (used for both fishing and diving). Boat ramps and marinas are shown, both as recreational sites and access points for response activities. Airports, ferries, and helipads are shown as access points.

Management Areas

Officially designated management areas include designated critical habitats, national parks, state and regional parks, Indian reservations, marine sanctuaries, Nature Conservancy lands, wildlife refuges, and preserves and reserves set aside by various agencies and organizations. Other ecological sites that have special resource management status can be included as "Special Management Areas."

Table 4. Commonly mapped human-use resources.

Data Element	Sub-Element	Mapped Areas
Recreation/Access	Access	Vehicular access to the shoreline
	Airport	Includes airports, landing strips, etc.
	Artificial reef	Attracts high concentrations of fish and divers
	Beach	High-use recreational beaches
	Boat Ramp	High-use marine/estuarine facilities
	Diving Site	High-use recreational areas
	Ferry	High-use ferry routes
	Helipad	Designated helicopter landing sites
	Marina	High-use marine/estuarine facilities
	Recreational Fishing	High-use recreational areas
	Surfing	High-use recreational areas
Management Areas	Designated Critical Habitat	Officially designated by USFWS
	Indian Reservation	Indian Reservations and Tribal Lands
	Marine Sanctuary	Waters managed by NOAA
	National Park	Land managed by NPS
	Nature Conservancy	Protected land owned by TNC
	Park	State and regional parks
	Special Management Areas	Usually water-associated
	Wildlife Refuge, Preserve, Reserve	Federally and state managed
Resource Extraction	Aquaculture Site	Hatcheries, ponds, pens, etc
	Commercial Fishing	Important, high-use areas
	Log Storage Sites	Areas of high economic importance
	Mining	Intertidal/subtidal mining leases
	Subsistence	Designated harvest sites
	Water Intake	Industrial; drinking water; cooling water
Cultural Resources	Archaeological Site	Water, coastal, or wetland-associated
	Historical Site	Water, coastal, or wetland-associated

Resource Extraction Sites

Resource extraction locations include aquaculture, commercial and subsistence fisheries, log-storage areas, mining-lease sites, and water intakes. Log-storage sites and intertidal and subtidal mining leases are included so that appropriate protection and cleanup strategies can be developed. Log-storage sites can contain large numbers of valuable wood products that, when oiled, must be cleaned at great expense before sale. Owners of intertidal mining leases must be contacted before removal of oiled sediment. For aquaculture, water intakes, and other economic resources, an owner and emergency contact name and telephone number may be listed.

High-value commercial fishing areas are also a critical component to ESI mapping, particularly leased shellfish beds and nearshore, shallow-water fisheries such as crabbing, shrimp harvest, lobster harvest, and estuarine fisheries. Often, the concern is to minimize impacts to the catch and fishing equipment as gear is pulled from the water through surface slicks. Non-commercial seafood harvest areas, including subsistence use areas, identify fishing sites and invertebrate collection areas that are often of great cultural and economic importance to local populations.

Cultural Resources

Cultural resources include archaeological, historical, and other sites of religious or cultural importance. The most sensitive types of cultural resources are those that are located in the intertidal zone, or sites located very close to the shoreline where they may be directly oiled or disturbed by response or cleanup activities. If there are multiple sites close to one another, than the general area is often indicated by one point or a series of points along the shoreline. However, many archaeological, historical, and cultural sites are location-sensitive, so the exact location of the site often cannot be disclosed. In such cases, the resources are often described in general in the introductory pages of the atlas and not shown at all; or a symbol in the general, but not the actual location of the site, is shown on the ESI map instead. It is important to note that users of ESI products must go the original source to obtain location-sensitive data.