Case Study: **Shoreline Habitat Classification for Northern California Current (NCC), Pacific Northwest Coast (PNWC), Northwest Atlantic Coastal and Marine (NAC-marine) Ecoregional Assessments**

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Purpose and region of analysis

The purpose of the described innovation was to generate coastal conservation targets through the utilization of existing shoreline classifications and tools to augment regional data sets. Existing shoreline classifications are generally based on substrate and wave energy; we have used these attributes as a surrogate or coarse filter for the conservation of the majority of intertidal species in an ecoregion. The ideal data for mapping shoreline ecosystems is biological data on the distribution and abundance of species in the intertidal and shallow subtidal zones. Unfortunately, these data are scarce across large geographies. t is our hope, however, that the coastal conservation targets generated from the methods described below can be associated with known biological data and therefore be predictive of shoreline ecosystem types.

The classification and subsequent target development has been utilized in various marine ecoregional planning efforts, including the Northern California Current, Pacific Northwest Coast, Coastal Forests and Mountains, and the Arctic Yukon, and the Northwest Atlantic Coastal and Marine region. This document describes the general approach for defining shoreline conservation targets based on NOAA's Environmental Sensitivity Index (ESI) data, and cites specific geographies in the continental U.S. for testing this approach.

Criteria/Methods

Marine conservation planning teams in California, the Pacific Northwest and the Northwest Atlantic coast are working together to develop a consistent approach for identifying shoreline conservation targets for use in ecoregional planning. This document provides general guidance on developing shoreline targets in a nested hierarchical approach that would allow for rollup of general targets over multiple regions, yet still allow for regional specificity in classifying targets. The approach utilizes the NOAA Environmental Sensitivity Index (ESI) database and builds on the ESI classification scheme (NOAA 1997). ESI was designed for ranking sensitivity of shoreline types to oil spills and is the best and most accurate coast-wide database for shoreline types; however, the classification scheme does not necessarily meet biodiversity conservation planning needs. The British Columbia ShoreZone classification (Howes et al. 1994), however, may be better suited for accurately identifying coastal biotic assemblages. ShoreZone identifies biophysical types that describe the substrate, exposure, and vegetation across the tidal elevation, as well as the anthropogenic features. The British Columbia and Washington ShoreZone data sets are built on shore types that aggregate precise community or habitat types according to their landform, substrate, and slope (Berry et al. 2001). ShoreZone identifies approximately 34 shoreline classes and 17 representative types. The recommended approach described below builds first on a distinction between rock, rock and sediment, sediment, and anthropogenic substrates that provide a foundation for other descriptors used to identify general shoreline types. Then various tools and decision rules are used to spatially define shoreline targets using a couple different methods. These variations described below all attempt to fulfill the following formula:

Substrate + Wave Energy = Biotic Assemblage

Guidelines for Classifying Shoreline Types

The following are recommended guidelines for cross-walking NOAA-ESI shoreline data to a consistent classification of shoreline conservation targets. This approach was first developed along the Pacific coast of North America, and is now being test along the North Atlantic coast. Note that there are a number of regions where ESI data have been assembled; every distinct geographic area may have entirely different environmental characteristics and therefore these guidelines may need to be revised to accommodate for them. Nevertheless, these recommendations aim to 1) promote consistent approach for identifying and naming shoreline types, 2) provide guidance on how to resolve multiple ESI types at a single location, and 3) develop working definitions of shoreline types.

We developed a general approach to building a Pacific west coast shoreline classification that is based on a crosswalk of the ESI types to a subset of regionally important natural shoreline types based on substrate or landform and sediment types (Table 1). These guidelines were then adopted along the Northwest Atlantic coast. To do this we extracted exposure or wave energy from the ESI types in order to examine substrate first, then add the exposure modifier back into the classification later or calculate a different set of wave energy classes. This framework has been modified from Howes et al. (1994) and Searing and Frith (1995). The two man-made shoreline types in ESI, seawall and riprap, would be retained as shoreline types but included as "cost factors" or human impact information incorporated into a suitability index rather than conservation targets in the planning process.

Substrate Type	Sediment	General Shoreline Types (may vary somewhat

	Type	regionally)
Rock[1]	N/A	Rock platform
	N/A	Rocky cliff
	N/A	Rocky shore
Rock & Sediment [2]	Gravel	Rock platform/shore/cliff with gravel beach
	Sand	Rock platform/shore/cliff with sand beach
Sediment[3,4]	Gravel	Gravel beach (or flat)
	Sand & Gravel	Mixed sand and gravel beach (or flat)
	Sand	Coarse-grained sand beach
	Sand	Fine-grained sand beach
	Sand/Mud	Tidal flat (mud flat or sand flat, if known)
	Sand/Mud	Marsh/Tidal Flat
	Mud	Marsh (brackish or saltmarsh, if known)
Anthropogenic	N/A	Seawall
	N/A	Riprap

Table 1: General shoreline categories (without exposure modifier)

Notes:
1. Rock: ESI does not distinguish slightly inclined or steep slopes for the bedrock landforms that do not contain sediment; if appropriate, combine "rocky shores" and "rock cliff" to form "rocky shores/cliffs."

2. Rock & Sediment: A combination of hard and soft substrate types form the basis of many ESI types. For example, while both ESI and ShoreZone systems recognize the (wave cut) rock platform type, in many cases the ESI type is found in combination with sand or gravel. Since the presence of sediment grains in combination with bedrock may result in a scoured rocky substrate, it may be important to retain the grain characteristics where they occur either above or below the rock platform and rocky shores. For example, a location with sand beach above or below a rock platform would be called "rock platform with sand beach" or “rock with sand beach.” For these cases, rocky platform, shore or cliff can be classed separately or lumped into “rock” with gravel or sand beach.

3. Grain size plays an important role in structuring beach communities and in use of beaches by shorebirds and other elements of biodiversity. At least three categories of grain-size should be used, if possible, when classifying beach types (gravel, sand and gravel, and sand); further subdividing sand beaches into fine and coarse grained beaches is also recommended.

4. Marsh or Tidal Flat types: to preserve important information, marsh types can be split out into “brackish” or “saltmarsh,” if known; similarly tidal flats can be specified as “mud flat” or “sand flat,” if known. In many locations, both marsh and tidal flat are present in the same locations and “marsh/tidal flat” should be considered a separate target.

Assessments should include brief definitions of the general shoreline types that were used. Some examples are provided below, modified from Ogborne 2003 and Berry et al. 2001 (note: general shoreline types within parentheses represent an aggregation of rock platform and rocky shore/cliff types where they contain sediment):

- **Rock platform**: Horizontal or near horizontal rocky intertidal areas >30 meters in width, with no organized beach features. A thin sediment veneer may be associated with these platforms or ramps but the veneer is typically patchy. Most commonly associated with rock outcrops

- **Rocky shore/cliff**: Shallow or steeply sloped rocky shores (>20°) or vertical rocky cliffs, with no organized beach features. Small pockets of sediment occur sporadically within the indentations along the coast

- **Rock platform w/ sand beach** (or **Rock w/ sand beach**): Rock platform, but with associated fine-medium-or-coarse grained sand beach either landward or seaward in the intertidal. Sand content may be >90%. The beaches typically occur in the middle to upper intertidal zones and may include log deposits in the supra-tidal zone. Distributions may be patchy, occurring intermittently along the coast within small indentations.

- **Rock platform w/ gravel beach** (or **Rock w/ gravel beach** or **Rock w/ sand & gravel beach**): Rock platform, but with associated gravel or mixed sand & gravel beach either landward or seaward in the intertidal. Rock and pockets of clastic sediments (rubble, boulder, cobble or pebble beach) including sand beaches; they typically occur on well- developed beach forms, such as berms or beach terraces, or as large patches of sediment in an otherwise rocky shoreline. Beaches typically occur in the middle to upper intertidal zones and may include log deposits in the supra-tidal zone.

- **Rocky shore/cliff w/ sand beach** (or **Rock w/ sand beach**): Rocky shore/cliff, but with associated fine-medium-or-coarse grained sand beach either landward or seaward in the intertidal. Sand content may be >90%. The beaches typically occur in the middle to upper intertidal zones and may include log deposits in the supra-tidal zone. Distributions may be patchy, occurring intermittently along the coast within small indentations.

- **Rocky shore/cliff w/ gravel beach** (or **Rock w/ gravel beach** or **Rock w/ sand & gravel beach**): Rocky shore/cliff, but with associated gravel or mixed sand & gravel beach either landward or seaward in the intertidal. Rock and pockets of clastic sediments (rubble, boulder, cobble or pebble beach) including sand beaches; they typically occur on well- developed beach forms, such as berms or beach terraces, or as large patches of sediment in an otherwise rocky shoreline. Beaches typically occur in the middle to upper intertidal zones and may include log deposits in the supra-tidal zone.

- **Gravel beach**: Sediments comprised of boulder, cobble, and/or a pebble mixture with <10% sand content. Beach slopes are in the range of 5° to 20° with the berm the steepest part of the intertidal zone. Because of the low sand content, these beaches are highly permeable. Gravel beaches are steeper in the lower intertidal zone; lower to middle intertidal zones are commonly armored.

- **Sand & gravel beach**: Sediments are a mixture of boulders, cobbles, pebbles and sand (with >10% sand and >10% gravel). Middle to high intertidal is commonly armored with sand in the subsurface. Beach slopes are in the range of 5^{o} to 20^{o} with the berm the steepest part of the intertidal zone. Lower to middle intertidal zones are commonly armored by cobbles with the sand layer in the subsurface. These beaches usually have similar permeabilities to sand beaches.

- **Sand beach**: Sediments <10% gravel and >50% sand; sediments are highly mobile in moderate to high wave energy. Beach slopes are in the range of 5^{o} to 20^{o} with the berm the steepest part of the intertidal zone. Beach permeability may range from high to low depending on the mud content of the beach. Ridge and runnels or swash bars may occur in the lower or middle intertidal zones.

- **Tidal flats** (sand, gravel, sand & gravel, or mud): Slopes are low, in the range of 5^{o} to 20^{o} with the berm the steepest part of the intertidal zone. May be composed of sand (<10% gravel and >50% sand), gravel (<10% sand), sand & gravel (>10% sand and >10% gravel) or mud (<10% gravel and > 50% mud). **Gravel flats** in the lower to middle intertidal zones are commonly armored, and because of the low sand content these beaches are highly permeable. Beach permeabilities for **sand flats** may range from high to low depending on the mud content of the beach. Multiple ridge and runnels or swash bars are common in the lower or middle intertidal zones. **Sand & gravel flats** typically have < 5^{o} slope with the berm the steepest part of the intertidal zone. Lower to middle intertidal zones are commonly armored by cobbles with the sand layer in the subsurface. These beaches usually have similar permeabilities to sand beaches. Berm sediments for **mud flats** are located near the high-tide mark and are usually coarser than those of the beach flat. Beach permeability is low due to the high mud content.

- **Marsh** (also referred to as **estuaries**, **organics/fines** or **lagoons**): Includes both brackish and salt marsh habitats; vegetation type depends in large part on freshwater input to the estuary. **Marshes** frequently rim the estuary at the high water mark. Brackish water conditions are common due to freshwater input to the estuary from stream runoff. Typically confined to low wave exposure environments. **Estuaries** are characterized by high variable distributions in texture, although muds and organics are common. (Note: estuaries are typically mapped in terms of area, although in both ESI and ShoreZone they are also mapping linearly. This has presented some challenges in terminology. For this exercise we refer to estuaries as area-based, containing fine sediment types and organic material.)

- **High Tide Lagoons**: Lagoons that have a tidal influence.

- **Channel**: A current dominated region in the intertidal area as opposed to a wave dominated area in the intertidal area composed of either bedrock or sediment substrate.

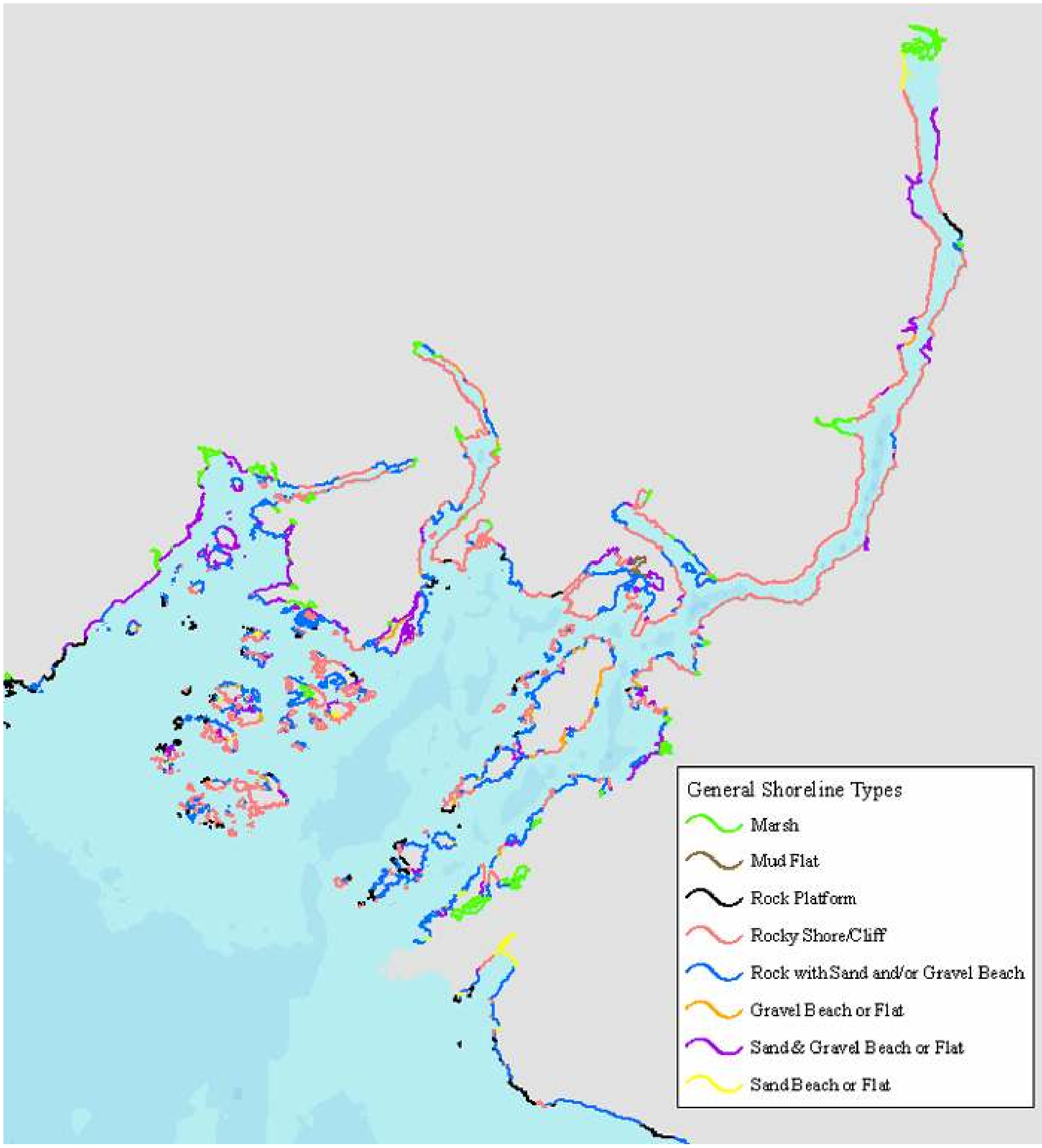

Figure 1: General Shoreline Types in Barkley Sound, west coast Vancouver Island, British Columbia, Canada.

Wave Energy or Exposure

Exposure is a very important factor structuring shoreline ecosystems. There are generally two approaches to including exposure classifications in shoreline targets that should be evaluated before developing regional shoreline classes. First, the ESI classification scheme includes exposure modifiers ("exposed" or "sheltered") on many shoreline types. For example, some rocky shores are classified as "exposed" or “sheltered”; however, in some cases not all rocky shore lengths are classified, so the user has to identify a default classification. It is important to read the underlying ESI descriptions to better understand the appropriate use of these exposure modifiers in the classification scheme. For California, the ESI exposure modifiers for rocky shores and tidal flats were considered sufficient to add to the classification scheme for some targets (rocky shores/cliffs/platforms and tidal flats). In the Pacific Northwest and Northwest Atlantic coast regions, however, planning teams decided that the ESI wave energy modifier should be removed and a calculated fetch be added to the general shoreline types.

There are various wave energy or fetch models available to calculate exposure, as well as different methods for classifying the results. For the Pacific Northwest and Northwest Coastal and Marine ecoregional assessments, we chose to use a model developed by LTL Limited (Victoria, British Columbia, Canada) and classify fetch results into four exposure classes. These classes include "very exposed," "exposed," "protected" and "very protected." The maximum and effective fetch calculations are classified using Morris (2001). Two additional exposure classes, "semi exposed" and "semi protected," can be added depending on the desired number of total targets for the ecoregion. We generally recommend aggregating the “exposed” class into “semi exposed,” and the “protected” class into “semi protected.” The exposure classes defined by the fetch model should be added to the shoreline types after the ESI crosswalk (e.g., exposed rocky shore/cliff). The exposure and shoreline combinations should be evaluated to remove any implausible combinations (e.g., very exposed marsh), and a comparison should be made with the original ESI exposure modifier. Figure 2 illustrates results of the aggregated fetch calculation in the Northwest Atlantic ecoregion.

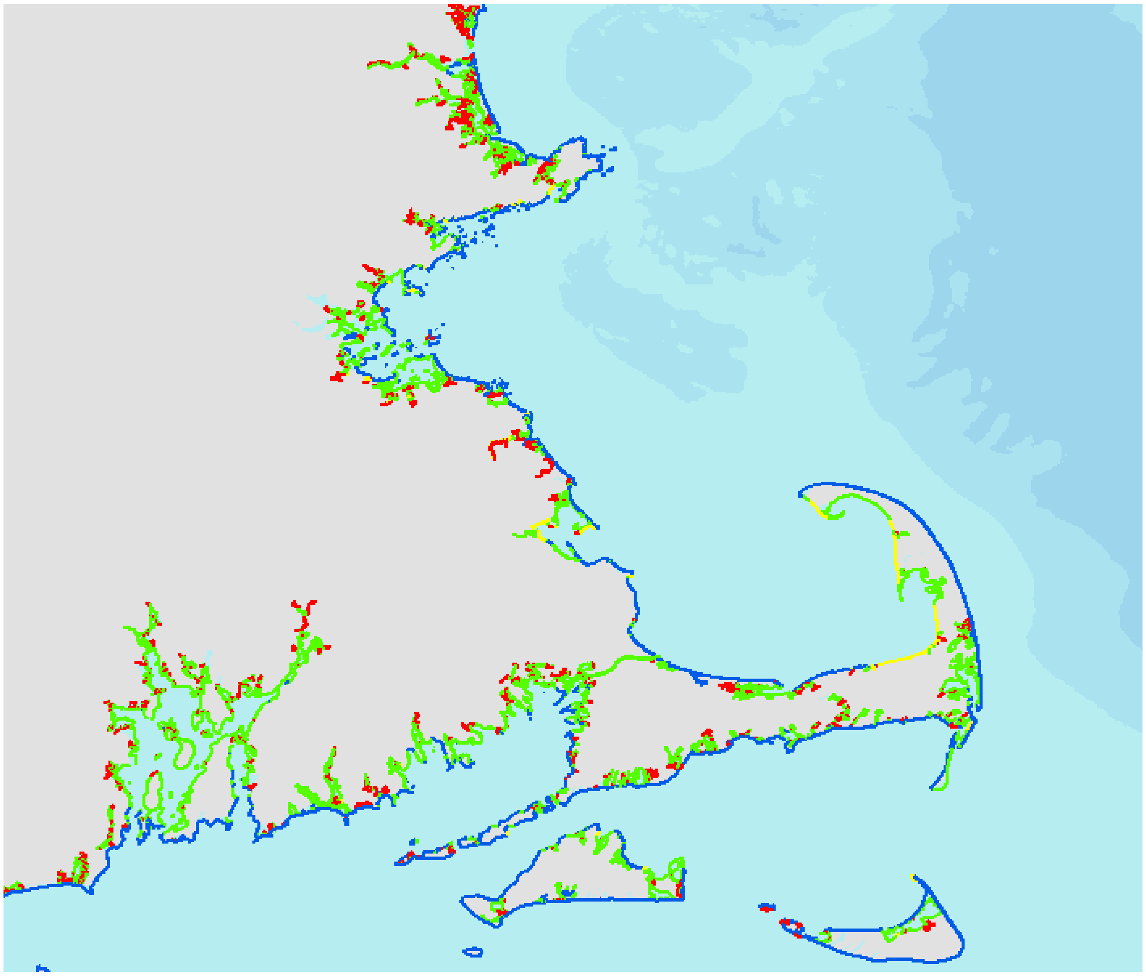

Figure 2: Raw fetch output for Massachusetts and Rhode Island shorelines. Blue shorelines are very exposed; yellow shorelines are exposed to semi-exposed; green shorelines are semi-protected to protected; red shorelines are very protected.

Nearshore bathymetry and prevailing winds are important factors to consider when refining output from the fetch model. The fetch model calculates the amount of water mass in front of each shoreline segment regardless of nearshore water depth or wind direction. Therefore the output may indicate an exposed bay from the perspective of water energy hitting beach, but if the water is very shallow then the amount of energy may be less of a factor than local bathymetry and slope. Other characteristics to consider include coastal topography and regional variation (e.g., fjord systems surrounded by high relief and glaciers).

Combinations of ESI Types

Often the ESI database identifies several shoreline types present at the same location as combinations, described from landward to seaward in orientation. It is well recognized that errors exist in the identification of multiple types at a single location, and that an aggregation exercise is warranted given the number of unique combinations. Aggregating these unique combinations into a reasonable number helps to clearly identify shoreline types and combinations that are representative of a specific ecoregion. Rather than favoring the seaward or landward type, we recommend evaluating two alternate approaches for cross-walking ESI data to the general shoreline types listed above: 1) identify which types or important combinations of types are rarest or of highest ecological significance and use a set of decision rules to identify a single type (or combination) at each location, or 2) identify types of highest ecological significance and ones representative of the specific region, but do not emphasize rare combinations. In this approach the data is used to represent a diversity of shoreline types and rarity is regarded as potential errors given the objectives of data collection (NOAA 1997). However, a set of decision rules to identify a single type (or combination) at each location is used in a similar fashion. These two approaches are discussed below:

1. Identify Rare and Ecologically Significant Shoreline Types: For the Northern California ecoregional assessment, decision rules for identifying the most important shoreline component at each location were based on biodiversity value and rarity of shoreline types. Marshes and tidal flats are two systems in California that have been the most impacted by coastal development; over 90% of the coastal marshes have been lost. Of the whole Northern California shoreline, 17% was classified as marsh or tidal flats, 30% as rocky shorelines, and 43% as beaches; sheltered rocky shores were the rarest type in the region. As an example, the general decision rules applied to the classification included:

- Marsh and tidal flats took precedence over rocky shores which took precedence over beach types; however, sheltered rocky shores took precedence even over marsh and tidal flats due to their rarity (e.g., Sheltered rocky shores > marsh /tidal flat > rocky > beaches).
- When marsh and tidal flats co-occurred, they were both retained in a "tidal flat / marsh" category.
- Rocky cliffs took precedence over rock platforms when they co-occurred, as they were less common.
- For beach types, the order of precedence for co-occurring types was: fine-medium grained > coarse > mixed > gravel, since fine-grained beaches tend to have associated communities that are more biodiverse.
- Very rare combinations that were found in very few places were collapsed to the single rarer type (e.g., "exposed rocky cliff/beach" in California was collapsed to "exposed rock cliff").

2. Identify Ecologically Significant and Representative Shoreline Types: The emphasis in this approach is to identify ecologically significant shoreline combinations (e.g., marshes with or without associated tidal flats, giving them precedence in the target selection and goal setting stages) and attempt to adequately represent rocky coastlines, beaches and tidal flats. For the Pacific Northwest Coast shoreline, 30% was classified as marsh or tidal flats, 53% as rocky shorelines, and 17% as beaches (Figure 3). The decision rules below are very similar to the first approach, minus the precedence to rare types.

- Marsh and tidal flats took precedence over rocky shores which took precedence over beach types; however, rock platforms with or without associated sediment (e.g., gravel beaches/wave-cut platforms/tidal flats) took precedence over tidal flats because of the ecological significance of platforms.
- Rarity was not highlighted during target selection because methods for gathering this information have produced many known errors (i.e., imagery is not taken during ESI flight surveys, but delineated directly on to USGS maps; therefore there is no way to review imagery and calculate error).
- When marsh and tidal flats co-occurred, they were both retained in either a “marsh/sand flat” category (for exposed tidal flats) or a "marsh/mud flat" category (for sheltered tidal flats).
- Rock platforms took precedence over rocky shores when they co-occurred as they are known to be more diverse in fauna.
- For beach types we aggregated fine, medium and coarse-grained beaches in order to reduce the number of targets.

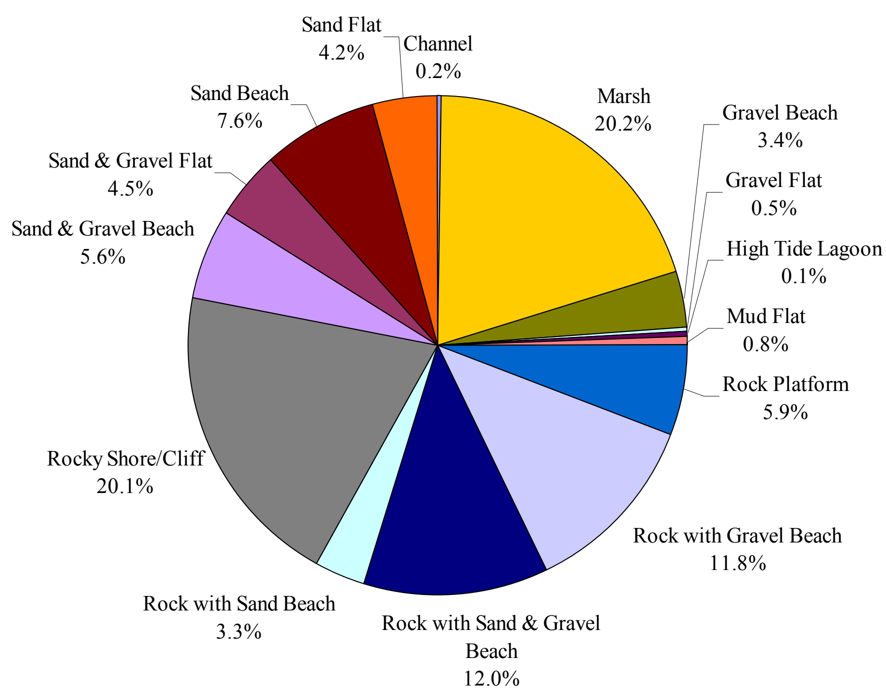

Figure 3: Distribution of general shoreline types of the Pacific Northwest Coast ecoregion. The second approach to aggregating unique ESI combinations is to emphasize more ecologically significant types (e.g., marshes, rock platforms) and attempt to adequately represent rocky coastlines, beaches, and tidal flats during target selection and goal setting phases.

Adding a Typology to the General Shoreline Types

A further refinement can be made to the general shoreline types by adding a typological association to them. For example, in the Pacific Northwest Coast we had two typologies, “embayment” and “outer coast.” Therefore any shoreline type within an enclosed embayment was identified (e.g., gravel beach embayment), and the same type was also identified on the outer coast outside of these enclosed areas (e.g., gravel beach outer coast). This allowed us to be more spatially explicit in representing shoreline targets in two distinct geographies of the coastal environment.

Man-made Structures

If man-made structures are present with other more natural shoreline types, use the natural shoreline type classification as the conservation target, but retain the man-made structure as a "cost factor" in the analysis. These cost factors are built into site selection algorithms as part of a suitability index which includes shoreline and adjacent land impacts, and factors associated with managed lands and waters. For example, ESI type "10A/8B" would be called “marsh” but that location would have an associated cost for the seawall or coastal structure component.

Products/Outcomes

The general approach for identifying shoreline targets should include a consideration of substrate type and sediment type first (as rollup categories that apply across multiple scales) and then identification of general shoreline targets that are relevant to regional environmental conditions. Each region may have a slightly different approach for developing shoreline targets from ESI data; however, the general shoreline types identified in Table 1 should provide a good starting point. The guidelines provided here should provide a framework for consistency, yet allow enough flexibility to meet regional planning needs.

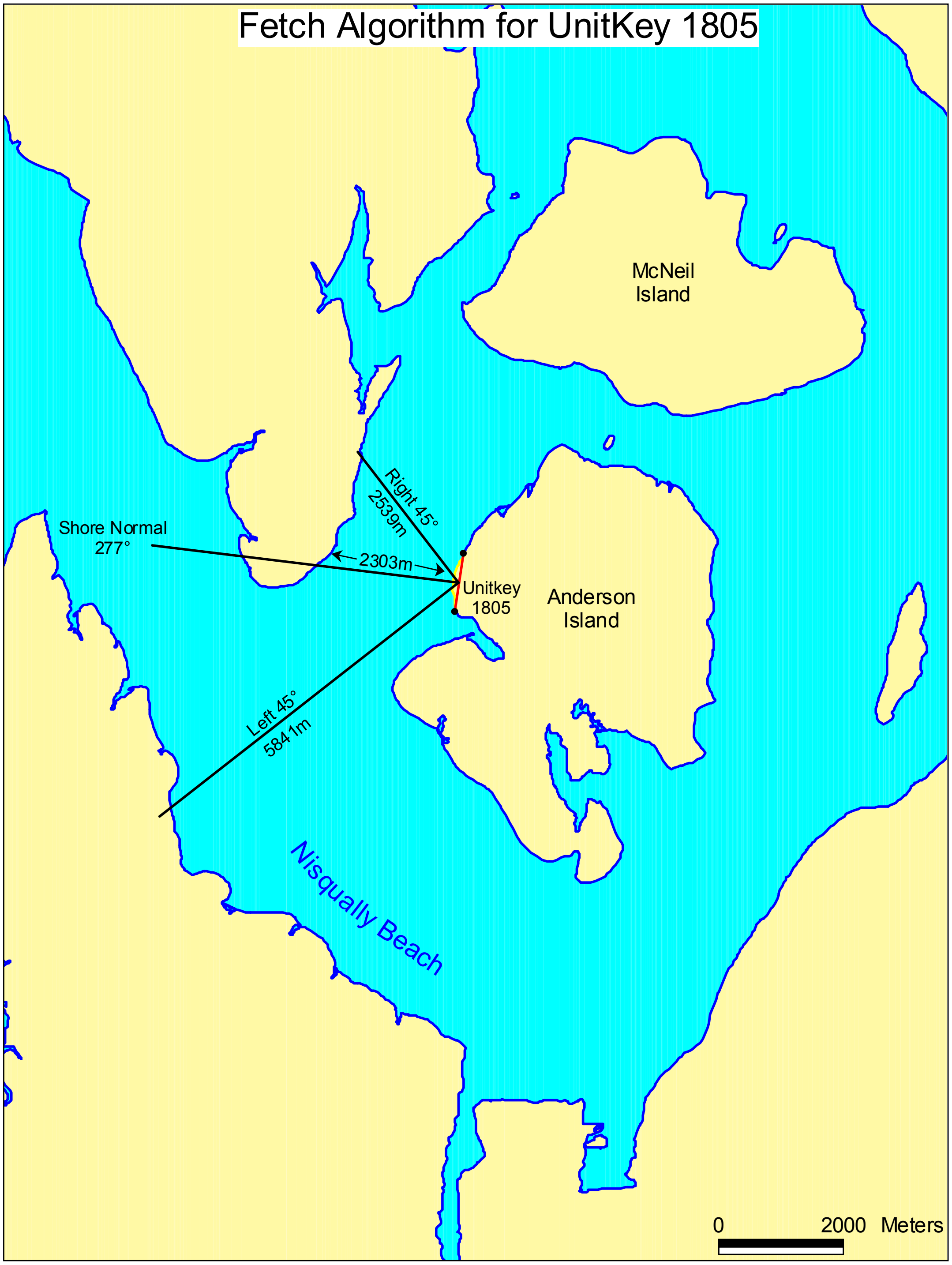

Figure 4: Illustration of the fetch calculation on a single shoreline segment, south Puget Sound, Washington (Courtesy LTL Limited).

Tools

The only tool used for this exercise was a model developed by LTL Limited (Victoria, British Columbia, Canada) for calculating fetch, or wave energy. This is a standalone program that works off of tables generated from ArcInfo coverages. There are other tools available to calculate fetch, but this tool does a decent job across large areas. It should be noted that this model calculates fetch based on the central node for any given shoreline segment (Figure 4). Therefore if the node happens to be directed toward land, though half of the segment is also direct toward open water (i.e., the segment wraps around a point or spit), the segment will get coded as relatively protected. This should be monitored closely, and results of this tool should be compared with ESI exposure modifiers. In addition, small islands with only one shoreline segment are not calculated. Please contact LTL Limited directly regarding this tool.

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