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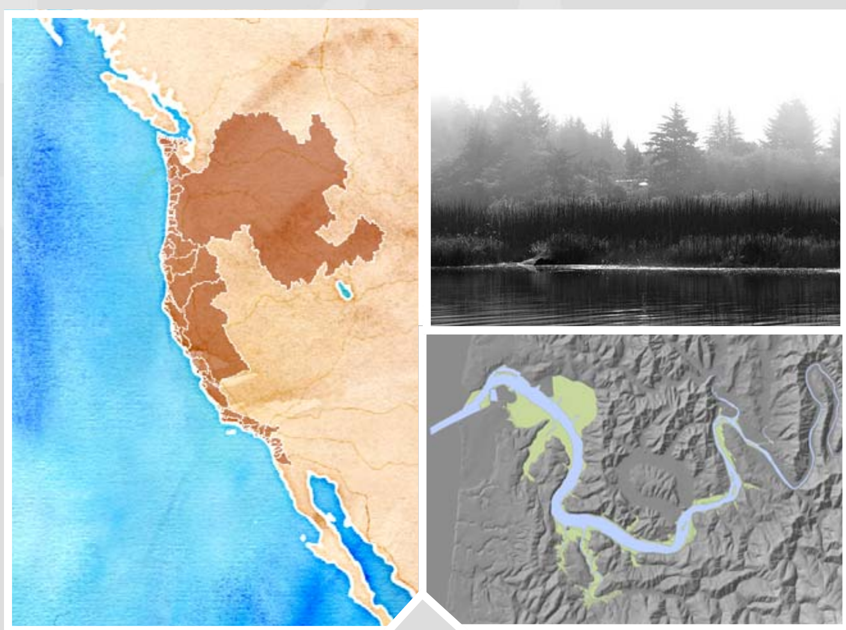
User's Guide and Metadata for WestuRe:
U.S. Pacific Coast Estuary/Watershed Data and R Tools



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User's Guide and Metadata for WestuRe: U.S. Pacific Coast Estuary/Watershed Data and R Tools

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Contents

US EPA ARCHIVE DOCUMENT

US EPA ARCHIVE DOCUMENT

1 Overview

There are about 350 estuaries along the U.S. Pacific Coast (U.S. Fish and Wildlife 2011). Basic descriptive data for these estuaries, such as their size and watershed area, are important for coastal-scale research and conservation planning. However, this information is spread among many sources, making it difficult to find and standardize. The goal of the WestuRe Project is to provide a framework to: (1) make general descriptive data for estuaries and their watersheds more accessible, and (2) provide tools to make analyzing and visualizing these data easier.

The WestuRe download includes data describing U.S. Pacific Coast estuaries and their corresponding watersheds from northern Washington (including the region located along the Strait of Juan de Fuca that goes from Port Townsend to Cape Flattery, 48.383°N) to southern California (Tijuana Estuary, 32.557°N), excluding Puget Sound proper and coastal islands (Fig. 1). The WestuRe data currently include shapefiles of estuary and watershed polygons as well as CSV files summarizing geomorphological and climate data (Fig. 2, Section 2). The WestuRe tools help users extract and view relevant data using the statistical program R and Google Earth (Fig. 3, Section 3).

Potential applications of the data include:

- Describing and comparing estuaries and watersheds at the landscape scale
- Identifying relationships between estuary/watershed variables
- Incorporating estuary/watershed attributes in models to predict species and habitat distributions
- Classifying estuaries according to morphology, climate, and habitat (Lee and Brown 2009)

Figure 1: Data includes estuaries along the U.S. Pacific Coast (yellow region).

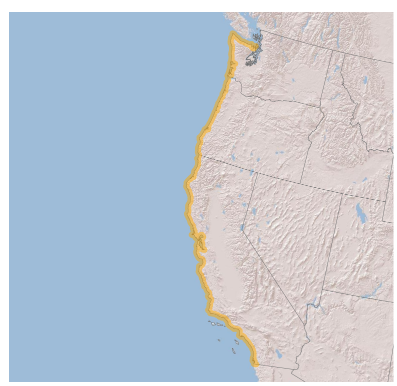
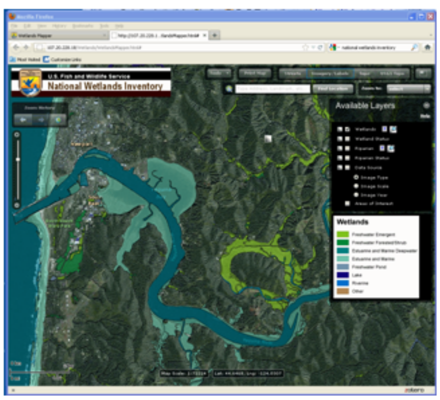


Figure 2: Overview of data (details provided in Section 2).

Estuary	Watershed	Climate
SHP & CSV files	SHP & CSV files	CSV files
We modified the geospatial NWI data (U.S. Fish & Wildlife 2011) to make it more conducive to estuary research by: (1) including only estuarine wetland habitats, and (2) assigning each habitat polygon an estuary ID so data for individual estuaries can be identified and compiled. In addition to the SHP files, a CSV file includes estuarine: name, state, latitude, longitude, total/intertidal/subtidal area.	The U.S. EPA (Lee and Brown 2009) delineated watersheds to capture the entire drainage area of each estuary (i.e., Estuarine Drainage Area, EDA). Coastal Drainage Areas (CDAs) that do not feed into an estuary were also identified. In addition to the SHP file, a CSV file includes watershed: type and area.	Monthly climate data are available for: (1) sea surface temperature outside the mouth of the estuary (Payne et al. 2011); (2) air temperature at the mouth of the estuary (Thornton 2009); and, (3) precipitation and air temperature data averaged over the watershed (PRISM Climate Group 2011).



Screenshot of NWI Wetlands Mapper for Yaquina Estuary, OR. The WestuRe estuary data is derived from the NWI.

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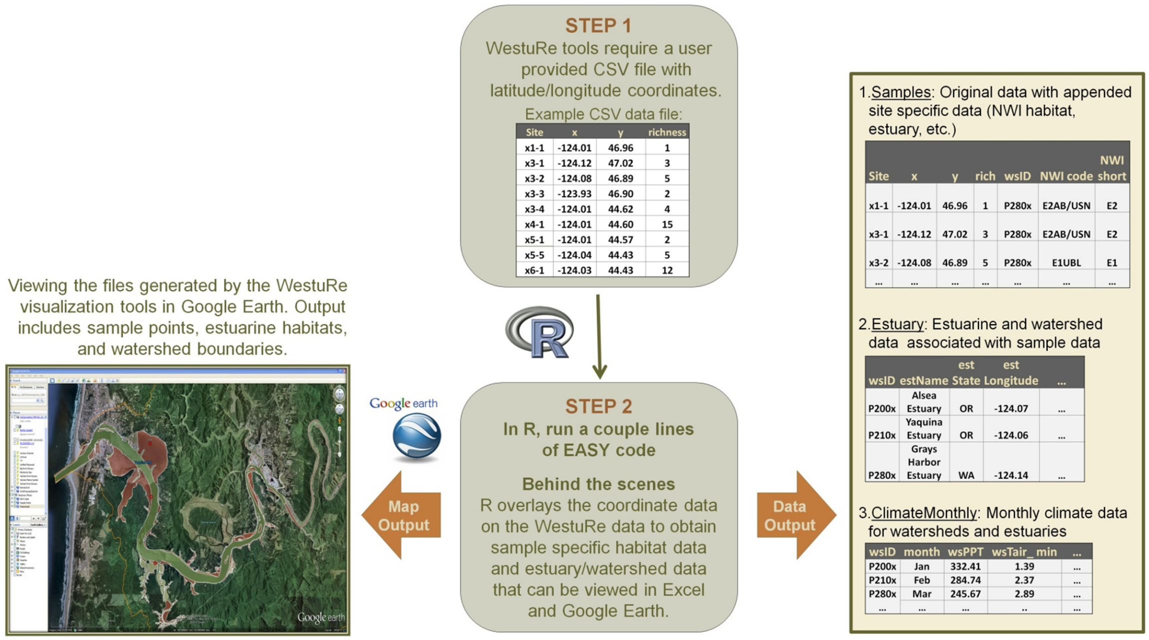
Figure 3: Overview of WestuRe tools for obtaining and visualizing estuary/watershed data using the statistical program R and Google Earth (details provided in Section 3).



2 The Data

WestuRe provides data and tools for analyzing and visualizing estuary and watershed data for the U.S. Pacific Coast (Table 1). In this guide, we provide a brief description of the WestuRe data files and maps, and how they were derived. Most of these data are updated from the U.S. EPA report, *Classification of Regional Patterns of Environmental Drivers and Benthic Habitats in Pacific Northwest Estuaries* (Lee and Brown 2009). This report inventoried the estuaries of the Pacific Northwest to develop a classification scheme to better understand the vulnerability of estuaries to anthropogenic nutrient loading. The *Classification Report* provides a more comprehensive description of the data and how it may be used to help assess estuarine vulnerability.

2.1 Estuary data

The estuary geospatial files and corresponding estuary geomorphology data in the WestuRe output are based on a modified version of the U.S. Fish and Wildlife Service's National Wetlands Inventory data (NWI, U.S. Fish and Wildlife Service 2011). The estuarine habitat data from the NWI is an excellent resource for analyses requiring regional scale data because of its extensive and con-

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Table 1: Files included in the WestuRe download.

Data (folder)	Contents	Size
EstMouths (folder)	Geospatial SHP and KML files of estuary mouthpoints based on NWI* estuarine habitats	N=349 estuaries + 2 Humboldt and 2 SF lobes$
NWI_WA (folder)	Geospatial SHP file of estuarine habitats in Washington	N=1516 polygon features
NWI_OR (folder)	Geospatial SHP file of estuarine habitats in Oregon	N=6698 polygon features
NWI_CA (folder)	Geospatial SHP file of estuarine habitats in California	N=10058 polygon features
Watershed (folder)	Geospatial SHP and KML files of U.S. Pacific Coast watershed boundaries	N=506 polygon features
NOAAsalinity (folder)	Geospatial SHP and KML files of U.S. Pacific Coast estuary salinity zones	N=36 estuaries (plus some bays)
EstuaryData (CSV)	Estuary data	N=349 estuaries + 2 Humboldt and 2 SF lobes$
WatershedData (CSV)	Watershed data	N=506 watersheds + Humboldt and SF combined lobes
ClimateMonthly (CSV)	Monthly climate data for watersheds and estuaries	N=508 x 12 months=6108
RFunctions (folder)		
Functions (R)	Code for *points2est* and *points2kml* tools that extend the utility of the estuary/watershed data	
MapColors (CSV)	Color data for visualizing estuary habitat data (internal file)	
Other Files		
ExampleData (CSV)	Example data used in SampleScript.R	
SampleScript (R)	Demonstration code for R tools	
SampleOutput (CSV)	Example output files generated by the *points2est* and *points2kml* tools using "ExampleData.csv" data	
Users Guide (pdf)	PDF describing the data and R tools	

*NWI refers to the U.S. Fish and Wildlife Services' National Wetlands Inventory (U.S. Fish and Wildlife Service 2011).
$Humboldt and San Francisco have additional data corresponding to their two estuary lobes.

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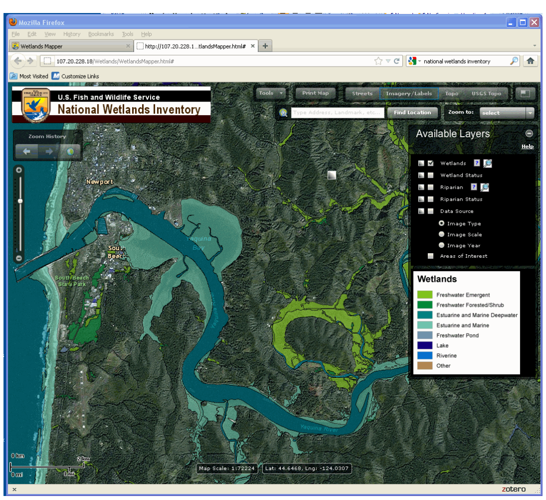
sistent geographic coverage. The NWI provides regional-scale maps of wetlands and deepwater habitats which are classified using a hierarchical system organized as System/Subsystem/Class/Subclass plus some additional modifiers (Cowardin et al. 1979, Appendix A). The habitat classes identified at the system-level include marine, estuarine, riverine, palustrine, and lacustrine (Fig. 4). These habitats are identified by analyzing high altitude imagery in conjunction with other data sources and field work. We modified the NWI geospatial data for estuarine research by including only habitat polygons classified as marine, estuarine, and tidal riverine. Furthermore, we assigned a unique Watershed ID to each estuary habitat polygon, that identifies its watershed (Section 2.2).

Figure 4: Screenshot of NWI Wetlands Mapper for Yaquina Estuary, OR.



Following Lee and Brown (2009), estuaries were defined as waterbodies containing an NWI estuarine polygon and directly discharging into the ocean. Semi-enclosed harbors or bays with only marine polygons and coastal streams with only tidal riverine polygons were not classified as estuaries. The NWI was revised in 2011, after the release of the Lee and Brown report, and several new estuaries were identified, particularly in California where 78 estuaries were added. One result of this revision is that there is no longer a strict one-to-one correspondence between all estuaries and watersheds, and some coastal drainage areas (CDA's) now contain one or more estuaries. For most users, this will be of little consequence because the newly added estuaries tend to be very small with an average area of 0.03 km^2. To prevent confusion, WestuRe only includes the estuarine area data for the 267 estuaries with unique watersheds.

Based on our analysis of the NWI data, there were 349 estuaries along the U.S. Pacific Coast, excluding Puget Sound, WA (Table 2). Descriptive statistics for each estuary were obtained by summing the NWI estuarine habitat polygons sharing the same watershed ID, for: intertidal, subtidal, tidal riverine, and in a few cases (based on best professional judgment), marine habitats. There is just over 3600 km^2 total estuarine habitat on the U.S. Pacific Coast (including the estuaries along the Strait of Juan de Fuca, but otherwise excluding Puget Sound). Extensive intertidal habitat is one of

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the defining characteristics of U.S. West Coast estuaries, with about 1380 km^2, or 38%, of the total estuarine habitat identified as intertidal. Intertidal habitat provides many valuable services including aquaculture and bird viewing opportunities (Lamberson et al. 2011). About 65% of the inventoried estuaries were smaller than 0.5 km^2, and the 4 largest estuaries (San Francisco, Columbia River, Willapa Bay, and Grays Harbor) account for about 83% of the total estuarine area (Fig. 5). Despite their diminutive size, small estuaries are included in these data because they provide critical habitat for salmon (Lackey 2004, Lackey et al. 2006a, 2006b, Lawson et al. 2004), and have ecological, economic, and cultural significance.

Table 2: Number of estuaries by state. Only estuaries with unique watersheds have estuary area data.

State	Estuary count: All	Estuary count: Unique watersheds[1]	Estuarine area: > 0.5 km^2	Estuarine area: >1 km^2
Washington[2]	40	38	14	8
Oregon	64	62	20	16
California	244	166	56	35
Columbia River[3]	1	1	1	1
Total	349	267	91	60

[1]Estuaries added in 2011 revision of NWI typically do not have a unique watershed

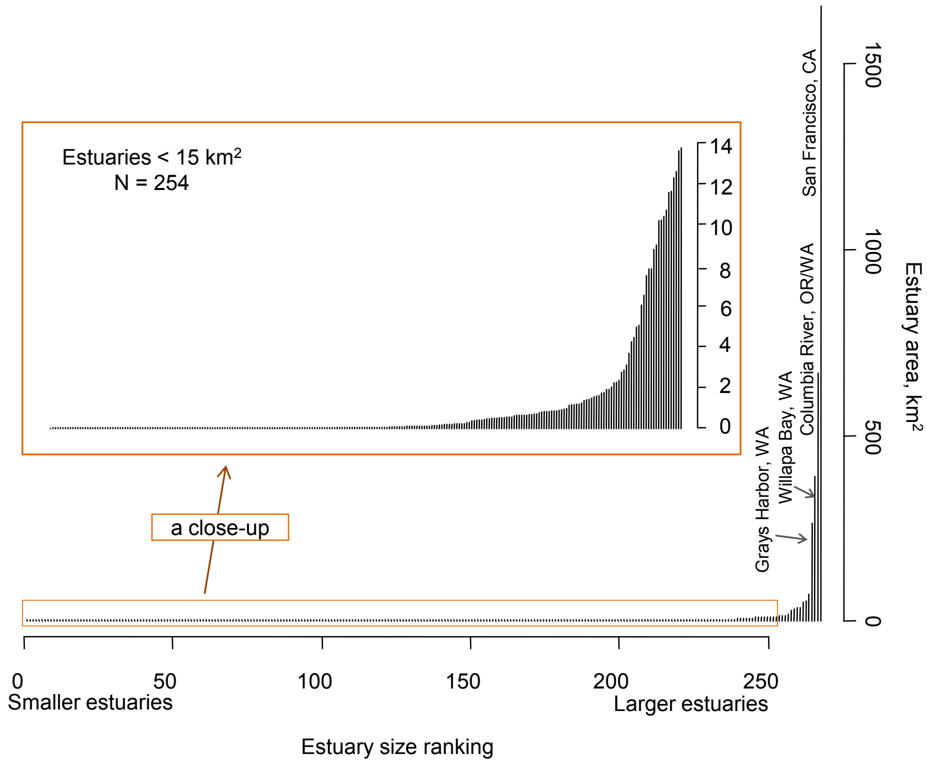
[2]Excludes Puget Sound

[3]Washington and Oregon

WestuRe provides the raw estuary data as CSV and SHP files located in the "Data" folder. The EstuaryData.csv file can be opened in Excel and contains descriptive spatial statistics for each estuary (Table 8). The geomorphological NWI habitat data are available as SHP files (NWI_WA, NWI_OR, NWI_CA) which can be visualized in Arc GIS, or other spatial software. The estuary mouthpoints are available as either a SHP or KML file (EstMouths). The KML version can be viewed in Google Earth. If the *points2est* tool is run in R, these data will be used to generate some of the data variables in the "Samples.csv" (Table 4) and "Estuary.csv" (Table 5) files that are returned. To generate the estuary data in "Samples.csv", R overlays the user provided sample points onto the NWI data to obtain the estuary names and habitats where the point falls. For "Estuary.csv", the descriptive data for estuaries that have sample points are returned. If the *points2kml* tool is run, maps of the estuarine habitat boundaries, watershed boundaries, and sample points are created for viewing in Google Earth.

Despite the overall high quality of the NWI data, there are some limitations (Lee and Brown 2009). Typically the NWI habitats are not as detailed or as accurate as those from habitat maps specifically developed for particular estuaries. The NWI habitat designations for some estuaries are based on limited field validation, and consequently, habitats may be misclassified. In particular, the designations between estuarine and tidal riverine polygons should be viewed cautiously. The demarcation between estuarine and tidal riverine polygons was defined by salinity, with the transition oc-

Figure 5: Distribution of estuary areas along the U.S. Pacific Coast (N=267). Most estuaries are smaller than 1 km^2. The four largest estuaries are San Francisco, CA; Columbia River, OR/WA; Willapa Bay, WA; and Grays Harbor, WA (from largest to smaller).



curring where salinity exceeds 0.5 during the period of annual average low flow. This boundary can be difficult to accurately identify even with ample field data, which is not available for many of the estuaries. Furthermore, some of the NWI data were generated in the late-1970s and early-1980s, and thus are historical snapshots of estuarine conditions. Estuaries are dynamic systems and the locations of their mouths and habitats may have changed over time. The habitat classification codes used by the NWI may not always be consistent among estuaries: in some cases, the codes may be obsolete; in other cases, the use of the more detailed modifiers is not consistent among estuaries. For certain types of analyses, it may be better to disregard the more detailed classifiers or to consolidate the codes into broader habitat classes as recommended by Lee and Brown (2009, Table 2-1). The U.S. Fish and Wildlife Service has an ongoing effort to update and improve the NWI data so some of these issues

US EPA ARCHIVE DOCUMENT

will improve over time.

2.2 Watershed data

The U.S. EPA (Lee and Brown 2009) delineated watersheds to create a one-to-one relationship between each estuary and watershed (Fig. 6). These data were derived from a watershed geospatial layer originally created for NOAA's Coastal Assessment Framework (NOAA 1999). Because the NOAA watershed boundaries were not sufficiently detailed for estuary-scale analyses they were further delineated using additional data (Lee and Brown 2009). The drainage area for each estuary was delineated (Estuarine Drainage Area, EDA[1]) to capture the entire landscape contributing to the nutrient loading of the estuary. Coastal Drainage Areas (CDA) that drain into the ocean but do not contain an estuarine polygon were also identified (Fig.6).

The delineation of watershed boundaries was based on estuaries identified in an earlier version of the NWI data. Due to updates of the NWI there are now a few mismatches between the estuarine and watershed geospatial data. Consequently, some estuaries are now located within CDAs, which by definition should not drain into an estuary. The WestuRe watershed data may be updated in the future to delineate watersheds for the new estuaries. However, the estuaries without a dedicated watershed tend to be very small (average size of 0.03 km^2), and consequently, the accurate delineation of watersheds may be difficult because the watershed areas tend to be overestimated for estuaries smaller than <0.1 km^2(Lee and Brown 2009).

About 506 EDAs and CDAs were identified, with a total drainage area of 850,000 km^2(and 308,000 km^2 when the Columbia River watershed is excluded) along the U.S. Pacific Coast (Table 3).

Table 3: Summary of U.S. Pacific coast watersheds.

Watershed Type	Definition	Count	Total Area (km^2)
Estuary Drainage Area (EDA)	Watershed draining into a single estuary	256	437,625
Coastal Drainage Area (CDA)	Watershed that does not drain into an estuary, but due to a recent update of the NWI, 39 CDAs contain one or more small estuaries	253	7,890

In general, larger estuaries have larger watersheds, with a general scaling relationship of[2]:

$$watershed \sim estuary^{0.77}$$

On average, an estuary that is twice as large as another will have a watershed that is about 70% larger (Fig. 7). Estuaries with relatively large watersheds for their size tend

[1]This is equivalent to merging NOAA's Estuarine Drainage Area (EDA, portion of watershed that empties directly into the estuary and is affected by tides) and Fluvial Dranage Area (FDA, portion of an estuary's watershed upstream of the EDA boundary) for an estuary.

[2]Reduced major axis regression model to allow for error in the independent variable (95% CI of 0.71-0.84, R^2 = 0.51)

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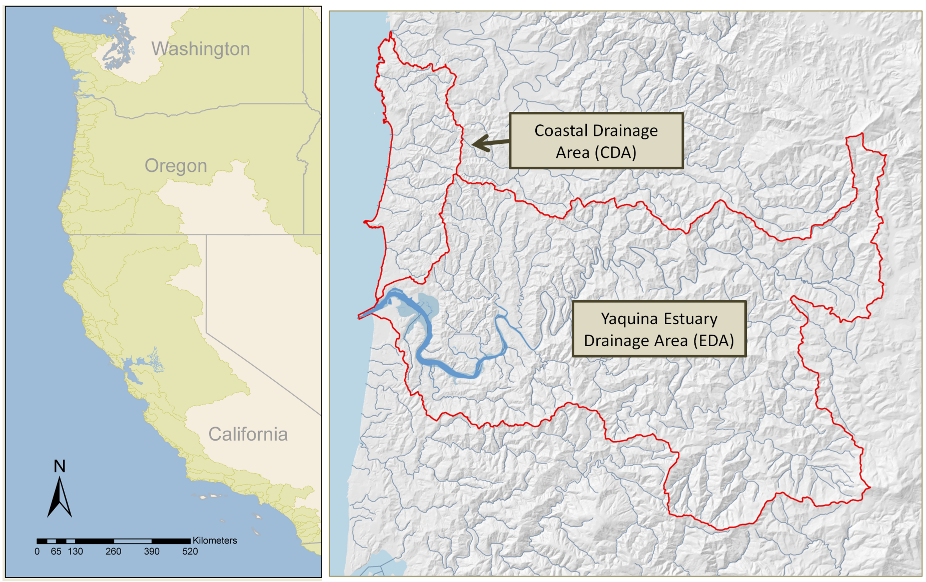
Figure 6: Watersheds of the U.S. Pacific Coast. Example of coastal drainage area (CDA) and the estuary drainage area (EDA) of Yaquina Estuary, OR.



to be more river-like; whereas, estuaries with relatively small watersheds tend to be more ocean-dominated. This is likely to have significant implications for an estuary's biota and susceptibility to certain types of stressors. This metric can be further refined by incorporating estimates of rainfall on the watershed (see Section 2.5).

WestuRe provides the raw watershed data as CSV and SHP files located in the "Data" folder. Watershed boundaries are available as either a SHP or KML file. The WatershedData.csv file can be opened in Excel and contains descriptive spatial statistics for each EDA and CDA (Table 9). If the *points2est* tool is run in R, these data are used to generate the watershed variables in the "Estuary.csv" file (Table 5) that is returned.

Some complexities of the watershed data are worth noting. The Humboldt and San Francisco estuaries are both comprised of two estuarine lobes with discrete watersheds. Depending on the analysis, it may be appropriate to treat these lobes as separate systems and analyze them independently. To allow the most flexibility, we provide data for the individual lobes as well as for the combined estuaries. Humboldt's northern "Arcata Bay" is supplied by watershed P130x02 and southern "Humboldt Bay" is supplied by watershed P130x01. San Francisco's northern bay is supplied by P090a and the southern bay by P090w. The Columbia River watershed extends into Canada, affecting the availability of some data

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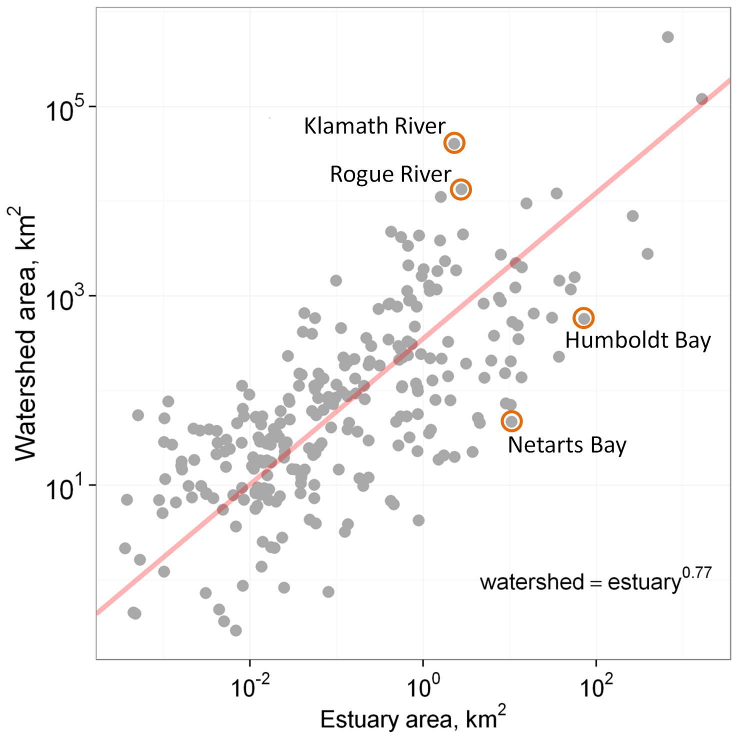
Figure 7: Relationship between estuary and watershed area. Estuaries above the line (e.g. Klamath and Rogue Rivers) tend to be more river dominated. Those below the line tend to be more ocean dominated (e.g. Humboldt and Netarts Bays).



parameters. Specifically, the watershed climate data for the Columbia River does not include the Canadian region.

2.3 NOAA salinity zones

We provide the salinity zones from NOAA's Coastal Assessment Framework (NOAA 1999), describing the average annual and depth averaged salinity concentrations for 36 U.S. Pacific Coast estuaries (plus some bays). These zones drive the distribution of biological communities and contribute to the understanding of estuarine circulation. The salinity concentrations used to demarcate the zones were: 0.0-0.5 ppt = tidal fresh zone; 0.5 to 25 ppt = mixing zone; >25 ppt = seawater zone. The zone boundaries were based upon salinity data from published and unpublished sources as well as discussions with experts. The "best guess" of informed experts was often necessary because the data required to estimate the location of these features were incomplete or nonexistent (National Estuarine Inventory 1985). Salinity zones are spatially and temporally variable due

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to factors that affect salt water intrusion and fresh-water inflow such as tides, rainfall, and wind.

The NOAA salinity zone maps are provided as SHP and KML files (Salinity Zones-NOAA). If the *points2est* tool is run, R overlays the coordinates of the user provided sample points onto the NOAA salinity zone map to obtain the salinity zone of each sample. These data are included in the "Samples.csv" file that is returned (Table 4).

2.4 Climate data

Monthly climate data is summarized for: sea surface temperature outside the mouth of the estuary; air temperature at the mouth of the estuary; and air temperature and precipitation averaged over the watershed (Fig. 8). The raw monthly climate data for all watersheds/estuaries are provided in "ClimateMontly.csv" in the "Data" folder. If the *points2est* tool is run in R, these climate data will be summarized for the estuaries containing sample points and used to generate some of the data variables in the "Estuary.csv" (Table 5) file that is returned.

Sea surface temperature (SST)

The average monthly surface temperatures of the near-coastal waters of each estuary mouth were estimated using satellite based remote sensing observations from Advanced Very High Resolution Radiometer (AVHRR). These data were compiled into monthly means as part of the Pathfinder versions 5.0 and 5.1 Project (PFSST V50 and V51). From these data, the USGS has created a data product with monthly SST data for a >28 year period at a 4 km grid cell resolution for coastal regions within 20 km of the shoreline (Payne et al. 2011). From the USGS product, we extracted the SST data within 10 km of each estuary mouth and averaged the monthly values for a 28 year period from 1982 to 2009.

Estuary climate data

The monthly air temperature data (average, minimum, and maximum) at the estuary mouth were estimated using Daymet data (`http://daymet.ornl.gov/gridded`, Thornton 2009). Daymet is a model that generates daily surface weather data using daily observations of minimum and maximum temperatures and precipitation from ground-based meteorological stations which are modeled over the conterminous United States. Daymet provides daily climate data for the years 1980-2003 at a 1 km x 1 km resolution. For each estuary, the daily climate data nearest the mouthpoint coordinates were extracted. The daily data were then averaged across all years for each month to calculate monthly means.

Watershed climate data

The average monthly air temperature (average, minimum, and maximum) and cumulative monthly rainfall was estimated for each watershed using PRISM NORMALS climate model data (`http://prism.oregonstate.edu`, Daly et al. 2007, PRISM

Climate Group 2011). PRISM (Parameter-elevation Regressions on Independent Slopes Model) uses point measurements of climate data, elevation, and other data to produce continuous digital grid estimates of monthly climatic data. Hourly weather station data are used to determine the daily maximum and minimum temperatures for a 24-h local period. These daily observations are then aggregated to calculate the monthly average maximum and minimum temperatures. The PRISM data provides monthly data averaged over 1971-2000 at a resolution of 30-arcsec (800 m). To average the climate data across the watershed, we took the average of the raster cells within each watershed polygon, weighting the values by the percentage of each raster cell included within the watershed polygon. The average air temperature was calculated by taking the mean of the minimum and maximum air temperatures (see FAQ of PRISM website).

2.5 Area normalized freshwater flow

One important variable that can be estimated using the WestuRe data is an index for classifying tide- and river-dominated estuaries which is calculated by dividing the annual cumulative volume of rainfall over the entire watershed (m^3, PRISM climate data, Daly et al. 2007) by the area of the estuary (m^2). Using the annual cumulative volume of rainfall on a watershed results in a correlated index of freshwater flow into the estuary because not all the water flows into the estuary due to processes such as evaporation and percolation (Lee and Brown 2009). Once in the estuary, the extent that the freshwater mixes with ocean water is dependent partially on the volume of the estuary. Ideally, cumulative annual precipitation would be normalized by estuarine volume. In the absence of these data, estuary area is a reasonable proxy for estuary volume (Lee and Brown 2009). This index is calculated by the *points2est* tool for each estuary that contains a sample point and is included in the "Estuary.csv" (Table 5) file that is returned.

We used the cumulative volume of watershed rainfall to obtain an index for area normalized freshwater flow because these data are readily available for all estuaries - including small, ungaged ones. Moreover, despite the coarseness of this index, it appears to successfully capture key aspects of tide- versus river-domination as measured by salinity for estuaries in the Pacific Northwest (Lee and Brown 2009). Estuaries with low volumes of watershed rainfall relative to estuary area, have less seasonal variation in salinity as well as less variation along the main axis of the estuary. Furthermore, a positive relationship was demonstrated between this index and the variation in salinity over a tidal cycle at the mouth of seven target Pacific Northwest estuaries. Despite the advantages of this metric, estimates of freshwater flow derived using gaged stations and/or models will be preferable in many instances because they provide a direct estimate of freshwater flow (rather than

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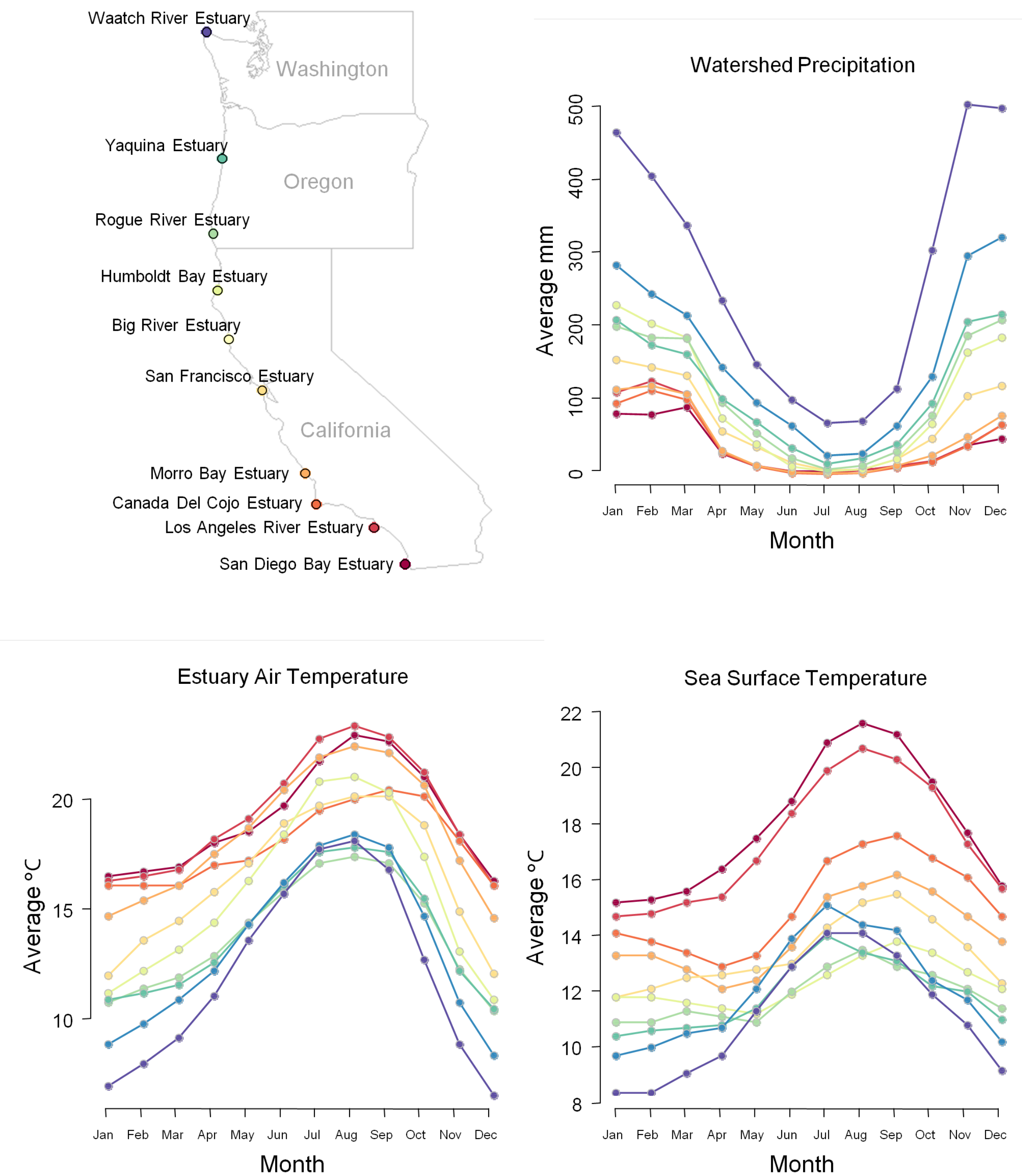
Figure 8: Monthly climate data for representative U.S. Pacific coast estuaries.



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a correlated index) and comparisons among estuaries may be more accurate. However, this method of estimating freshwater flow is not entirely free of assumptions given that flow is typically measured in a single or limited number of an estuary's tributaries.

Comparisons among estuaries will be most appropriate when they are located within the same ecoregion because the percentage of water that evaporates or percolates into the soil will be similar for these watersheds, such that a similar fraction of the rainfall will flow into each estuary. For example, most estuaries in the Pacific Northwest are probably comparable, with the possible exception of the Columbia River due to the large size of its watershed. Caution should be applied when comparing estuaries from different ecoregions such as Southern California and Pacific Northwest. Despite this complication, these comparisons may still be meaningful because large differences in rainfall between these two regions likely drive most of the variation in this metric.

Lee and Brown (2009) used the following preliminary thresholds to classify Pacific Northwest estuaries:

- Tidal-dominated: < 175 $m^3 m^{-2}$ $year^{-1}$
- Moderately river-dominated: 175 – 400 m^3 m^{-2} $year^{-1}$
- Highly river-dominated: > 400 m^3 m^{-2} $year^{-1}$

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3 The Tools

We have developed some tools to use within the statistical program R (R Development Core Team 2011) to help researchers:

1. associate their sample data to estuary and watershed data (*points2est*, Fig. 13)

2. visualize these data in Google Earth (*points2kml*, Fig. 14).

The WestuRe data is available without these tools (located in the “Data” folder), however, the tools provide a method of streamlining data acquisition and providing non-GIS experts with a way to map their data and view it in the context of other datasets.

These tools require the user to provide a dataset with latitude and longitude coordinates for sample points located within one or more estuaries on the U.S. Pacific Coast. The *points2est* tool aligns the sample coordinates with the geospatial watershed, NWI estuarine habitat, and NOAA salinity zone data, in order to return data specific to the sample points and the estuaries and watersheds where they are located (Tables 7, 9, 10). The *points2kml* tool takes an object created by *points2est* and outputs KML files (i.e., Google Earth) of the original sample points, NWI estuarine habitats, and watershed boundaries.

The WestuRe download includes some additional files that demonstrate how these tools are used. The SampleScript.R file is an R file that includes all the code needed to use the *points2est* and *points2kml* tools. This file will need to be modified for the user's computer/file configuration, the details of which are provided below. Also included is a sample dataset (ExampleData.csv) and the corresponding output files that are returned by the *points2est* and *points2kml* tools (File “SampleOutput”).

3.1 Program requirements

The freeware statistical program R is needed to use the WestuRe tools. R can be downloaded from: `http://cran.r-project.org/` (See: Appendix B for installation instructions; Section 3.5 for R terminology). The KML map files are viewed in Google Earth, which can be downloaded from: `http://www.google.com/earth/index.html`.

3.2 Starting R

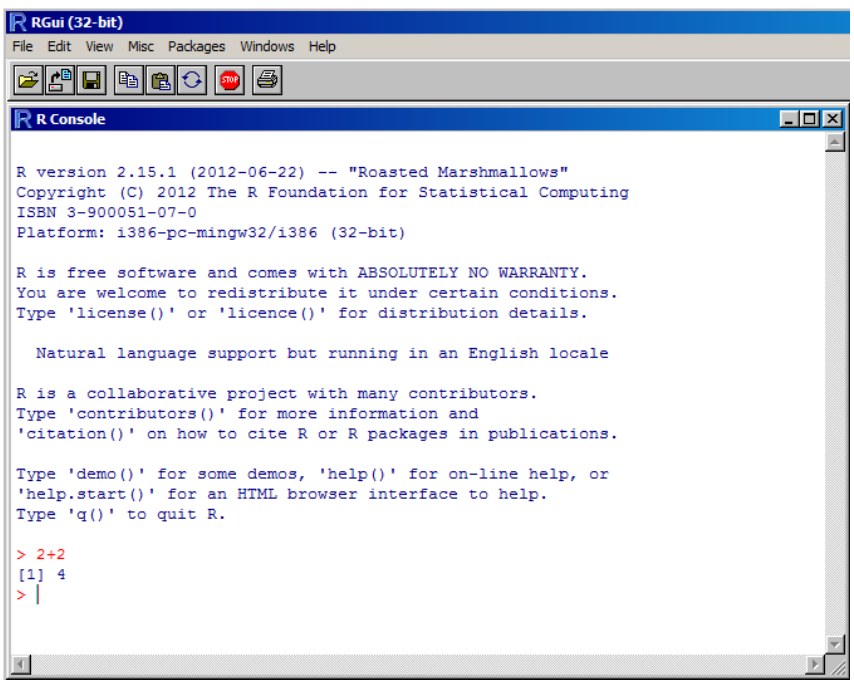
When you open R, you will see a rather sparse “R Console” (Fig. 9). To confirm that R is working, type 2+2 into the console and press enter:

```
2 + 2  #R returns the answer!

[1] 4
```

- The “>” is the “command prompt” where you input commands.
- The cursor is R telling you that it is ready to do your bidding.
- The output from R is blue and often preceded by a bracketed number.
- Anything preceded by a # (green in many text editors) is a user comment that R ignores. This is used to document your work.

Figure 9: R console with some code entered (2 + 2).



3.3 Input data

The WestuRe tools require a user supplied dataset that includes latitudes and longitudes of sample points from U.S. Pacific Coast estuaries. The data must be formatted as a CSV file (Fig. 10). A CSV file can be created from Excel using “Save As” and then selecting “CSV (Comma delimited)(*.csv)” from “Save as type:”.

US EPA ARCHIVE DOCUMENT

Latitude and longitude variables must be in decimal degrees. Methods of converting to decimal degrees can be found online (example: `http://en.wikipedia.org/wiki/Geographic_coordinate_conversion`) and can be done in R using *deg2num* from the **gmt** package. All longitude coordinates should be preceded by a "-" (negative sign), to indicate the data are located in the western hemisphere.

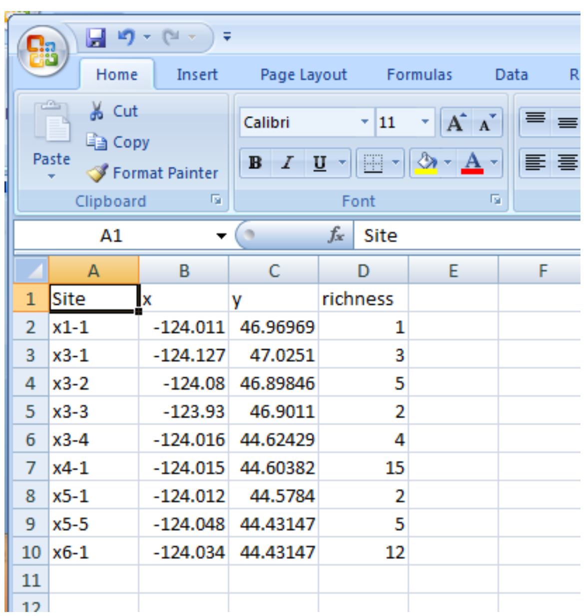
Correct format: 40.446195, -179.948862

Incorrect formats: 40°26'47"N, 79°58'36"W; 40:26:46N, 79:56:55W; 40.446195, 179.948862

Here are a few additional tips for preparing the CSV data file:

- Column names should be concise and contain no spaces
- Variables can be in any order, and there is no limit to the number of variables; however:
- It is better to cut variables that include extensive notes because they can sometimes cause errors when importing into R and when displaying in Google Earth
- Data with "#" symbols can cause import errors in R, and "&" symbols may cause errors in KML display

Figure 10: An example CSV file displayed in Excel that is ready for the WestuRe tools.



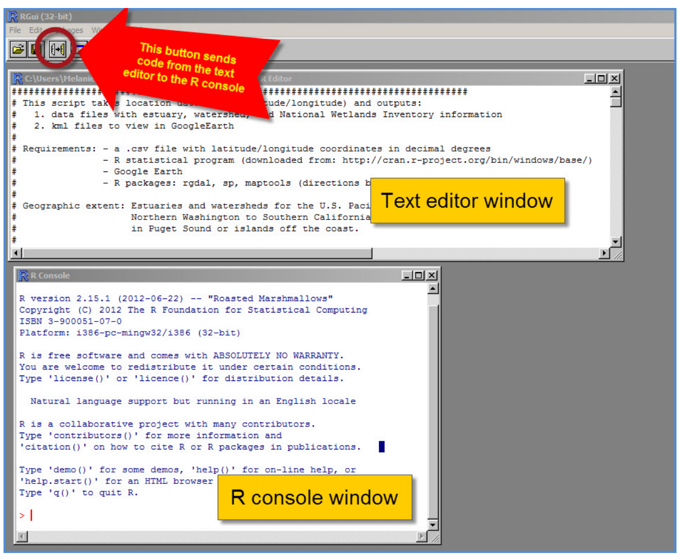
	A	B	C	D	E	F
1	Site	x	y	richness		
2	x1-1	-124.011	46.96969	1		
3	x3-1	-124.127	47.0251	3		
4	x3-2	-124.08	46.89846	5		
5	x3-3	-123.93	46.9011	2		
6	x3-4	-124.016	44.62429	4		
7	x4-1	-124.015	44.60382	15		
8	x5-1	-124.012	44.5784	2		
9	x5-5	-124.048	44.43147	5		
10	x6-1	-124.034	44.43147	12		
11						
12						

US EPA ARCHIVE DOCUMENT

3.4 R tools

The SampleScript.R file provides a template that guides you through the process of using the *points2est* and *points2kml* tools. To begin using the tools, open the SampleScript.R file in R: open R →File →Open script...→ and find the SampleScript.R file located in the WestuRe folder. This will open a 2nd window, called the text editor which will display some example code and additional instructions for using the tools (Fig. 11). In the SampleScript.R file, information proceeded by "#" are notes that are ignored by R, but provide useful information. To use the *points2est* and *points2kml* tools, you will need to make a few changes to the SampleScript.R file, which are described below. You will also need to be able to send lines of the code from the SampleScript.R file to the R Console. To do this, place the cursor at the appropriate line in the text editor and click the "Run line or selection" button (Fig. 11) or Ctrl+r.

Figure 11: R with SampleScript file open in the text editor window. Code is sent from the text editor window to the R Console by selecting the circled button.



STEP 0: Install packages

If you have not already done so, you will need to install the following packages: rgdal, sp, maptools (see Section 3.5 for a definition of "packages" and other terminology). These packages were developed to do spatial analyses and are necessary for the *points2est* and *points2kml* tools to work.

To download a package, either: 1) From the upper menu in R select: Packages → Install

US EPA ARCHIVE DOCUMENT

Packages; or, 2) go to the following line in SampleScript.R, and send the following code to the R console:

```
install.packages(c("rgdal", "sp", "maptools"))
```

R will ask which CRAN (Comprehensive R Archive Network) mirror site you want to use. Select one that is nearby. R will automatically download the packages and save them to its "library" folder located in the R Program Folder. You will only need to do this once, although, you may want to update your packages fairly frequently because many developers are making constant improvements.

STEP 1: Establish the directory path to the WestuRe folder

You will need to tell R the directory path for the WestuRe folder on your computer. In STEP 1 of the SampleScript.R, replace the existing directory path with the location of the WestuRe folder on your computer. Then, send the code to the R console. Unless told otherwise, the *setwd* (i.e., "set working directory") command established the location where R will search for and save files.

```
setwd("C:\\YourDirectoryPathToWestuRe")
```

NOTE: if you are using a Windows system, you will need to add an additional backslash ("\") between the folders in the directory path. Double backslashes are necessary because R uses a single backslash as an escape character. Make sure that the pathway is enclosed by quotes ("").

The best approach for identifying the directory path is to copy and paste it from the address bar that appears when you are within the WestuRe folder. This will help eliminate the mistakes that inevitably occur when typing a long path (Fig. 12).

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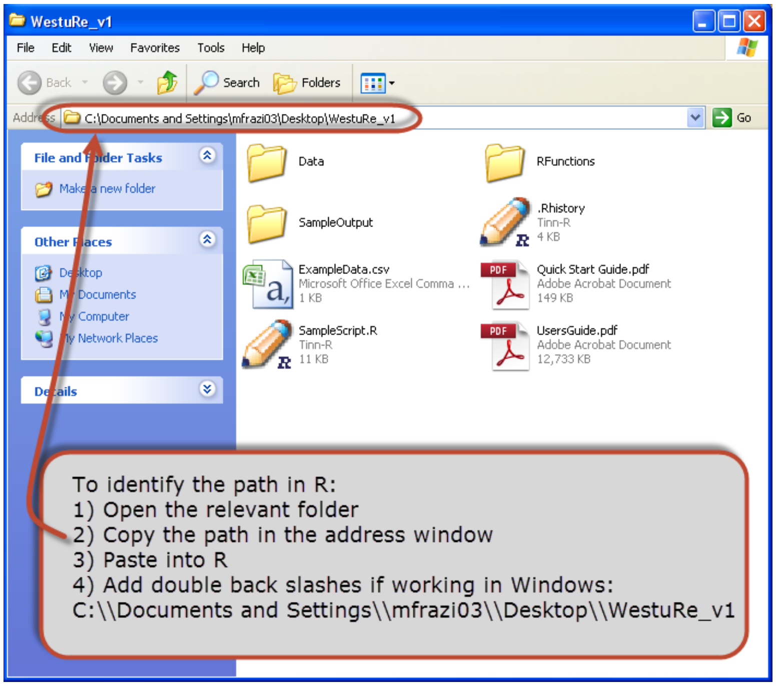
Figure 12: How to find a directory path in Windows systems.



STEP 2: Load the WestuRe tools

Now, R must be told to read the *functions.R* file in the *RTools* folder. This file contains the code for the *points2est* and *points2kml* tools. To make R read this file, send the following code to the R Console:

```
source("\\RTools\\functions.R")
# Feedback should be returned in the R
# Console: [1] 'estuary v. 1' [1]
# 'Loading necessary packages' Loading
# required package:....
```

STEP 3: Importing your data into R

In STEP 3 of the SampleScript.R document, replace the existing directory path with the location of the CSV file on your computer (Fig. 12). After the code is sent to the R Console, the data will be imported into R and called "MyData". The <- symbol is used by R to assign a name to an object, it can roughly be thought of as an equals sign.

US EPA ARCHIVE DOCUMENT

```
MyData <- read.csv("C:\\YourDirectoryPath\\YourData.csv")
```

If you don't have any available data, but still want to try the tools, send the following code to the R console:

```
MyData <- read.csv("ExampleData.csv")
```

In this case, R will import the "ExampleData.csv" file that is located in WestuRe folder.

Once the data have been imported into R, it is critical to check that everything is correct. If you have a short dataset, you can view all the data by typing the following into the R console:

```
MyData
```

However, if you have a longer data file, it is better to use commands such as:

```
head(MyData)  # returns first few lines of data frame object
tail(MyData)  # returns last few lines of data frame object
summary(MyData)  # returns summary of each variable
dim(MyData)  # returns number of rows and number of columns
```

STEP 4: *points2est*

The *points2est* tool (Fig. 13) aligns the user data with the spatial data and returns three CSV data files:

Sample Original user data with appended data for each point describing the estuary name, watershed ID, NWI habitat, and NOAA salinity class (for select estuaries) (Table 4)

Estuary Estuary and watershed data for estuaries with sample points (Table 5)

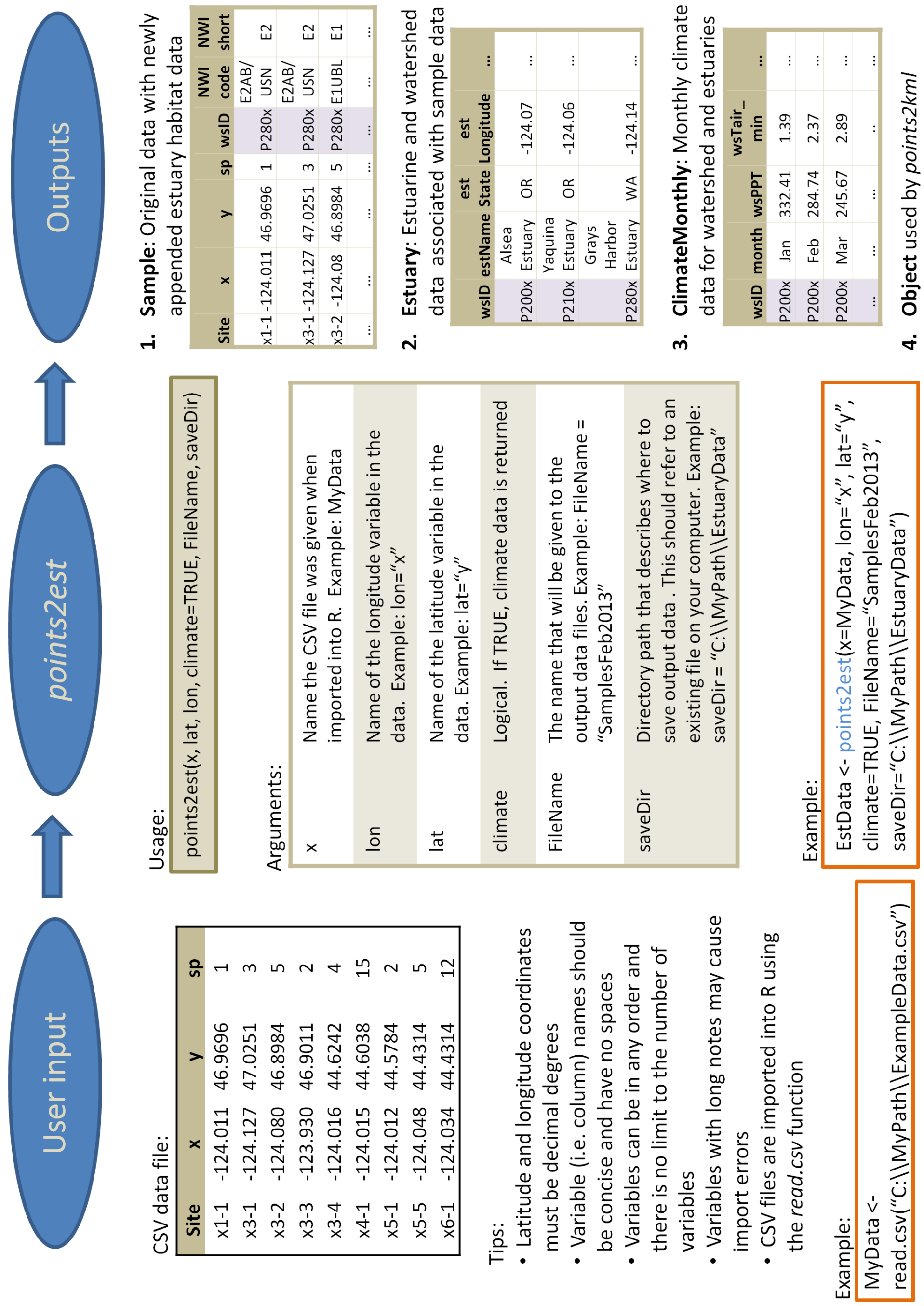
Climate Monthly climate data for estuaries with sample points (Table 10)

The data in the CSV files are linked by the unique watershed ID variable (wsID).

US EPA ARCHIVE DOCUMENT

US EPA ARCHIVE DOCUMENT

Figure 13: Description of *points2est* tool.



An example of the *points2est* tool:

```
EstData <- points2est(x = MyData, lon = "x",
    lat = "y", climate = TRUE, FileName = "SamplesFeb2013",
    saveDir = "C:\\MyPath\\EstuaryData")
```

The arguments are:

1. x = name of the data imported into R. Example: MyData (STEP 3)
2. lon = name of the longitude variable in the data. Example: lon = ”x”
3. lat = name of the latitude variable in hte data. Example: lat = ”y”
4. climate = TRUE/FALSE, if TRUE climate data are returned
5. FileName = a name for the output files. Example: FileName=”SamplesFeb2013”
6. saveDir = directory path describing where to save output files. Example: “C:\\MyPath\\EstuaryData”

In the above example, *points2est* generates 3 CSV data files that are saved in the directory: “C:\\MyPath\\EstuaryData”. In addition to these files, *points2est* creates an object that includes all the relevant geospatial data. In this case, the object is named “EstData”. You do not need to know anything about this object except that it can be used by the *points2kml* tool to create KML maps of the data.

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Table 4: "Sample" is a CSV data file generated by *points2est* that includes the following variables that are appended to the original data.

Variable	Description	Origin
wsID	ID of the watershed where the sample point is located	Modified from Lee and Brown (2009)
SalinityZone	Salinity zone where the sample point is located	NOAA's Coastal Assessment Framework
estName	Name of the estuary where the sample point is located	Derived by overlaying sample data on NWI geospatial data layer
NWIcode	The NWI habitat class at the location of the sample point	Derived by overlaying sample data on NWI geospatial data layer
NWIshort	The first two characters of the NWI habitat class. • E1 = estuarine subtidal habitat • E2 = estuarine intertidal habitat • M1 = marine subtidal habitat • M2 = marine intertidal habitat • R1 = tidal river habitat • NA = does not fall within an NWI estuarine polygon	Derived from the NWI geospatial data

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Table 5: "Estuary" CSV data file generated by *points2est*. NOTE: Estuary data is not returned in the few cases when there is more than one estuary in a watershed.

Variable	Description	Origin
wsID	ID of the watershed where the sample point is located	EstuaryData.csv (Table 8)
estName	Name of the estuary	EstuaryData.csv (Table 8)
estState	State in which estuary is located (WA, CA, OR)	EstuaryData.csv (Table 8)
estLongitude	Longitudinal coordinate of estuary mouthpoint (decimal degrees)	EstuaryData.csv (Table 8)
estLatitude	Latitudinal coordinate of estuary mouthpoint (decimal degrees)	EstuaryData.csv (Table 8)
estArea	Total area (m^2) of estuarine habitat within each watershed, calculated by summing the area of NWI polygons: E1, E2, R1, and occasionally, M2 (based on best professional judgment).	EstuaryData.csv (Table 8)
subtidalArea	Total area (m^2) of subtidal (E1) NWI polygons within an estuary	EstuaryData.csv (Table 8)
intertidalArea	Total area (m^2) of intertidal (E2) NWI polygons within an estuary	EstuaryData.csv (Table 8)
marineArea	Total area (m^2) of marine (M2) NWI polygons within an estuary. Typically, marine habitat was not included as part of estuarine area with the exception of a few bays. The decision to include M2 area was based on best professional judgment.	EstuaryData.csv (Table 8)
riverArea	Total area (m^2) of tidal influenced rivers (R1) NWI polygons within an estuary	EstuaryData.csv (Table 8)
estNotes	Comments related to data	EstuaryData.csv (Table 8)
Continued on next page.....		

US EPA ARCHIVE DOCUMENT

Table 5: ....Continued

Variable	Description	Origin
wsType	Describes relationship between watersheds and estuaries: **EDA** Estuarine drainage area, watershed delineation is defined by an estuary **CDA** Coastal drainage area. These typically do not contain an estuary. However, a few now include one or more estuaries due to revision of the NWI **When estuaries are located in a CDA, watershed data may not be meaningful.**	WatershedData.csv (Table 9)
wsArea	Area of watershed (m^2)	WatershedData.csv (Table 9)
wsNotes	Comments related to data	WatershedData.csv (Table 9)
wsPPT_cumulative	Cumulative yearly precipitation (mm) averaged over the watershed. Calculated by summing the average monthly rainfall data.	Derived from ClimateMonthly.csv (Table 10)
AreaNormFreshFlow	Area normalized freshwater flow (m^3 m^{-2} $year^{-1}$). Relative measure of freshwater flow through the estuary based on watershed precipitation data and estuary size. This variable is calculated by dividing the annual cumulative volume of rainfall over the entire watershed (m^3) by the area of the estuary (m^2), or *(wsPPT_cumulative x 0.001 x wsArea) / estArea*. See section on "Area-normalized freshwater flow" for more details.	Derived from ClimateMonthly.csv (Table 10)
wsTair_YearMean	Annual mean air temperature (°C) averaged over the watershed. Calculated by averaging the monthly watershed air temperature data.	Derived from ClimateMonthly.csv (Table 10)
estTair_YearMean	Annual mean air temperature (°C) near the estuary mouth. Calculated by averaging the monthly estuary air temperature data.	Derived from ClimateMonthly.csv (Table 10)
estSST_YearMean	Annual mean sea surface temperature (°C) outside the estuary mouth within a 10 km radius. Calculated by averaging the monthly sea surface temperature data.	Derived from ClimateMonthly.csv (Table 10)

US EPA ARCHIVE DOCUMENT

STEP 5: *points2kml*

Points2kml (Fig. 14) uses the object created by *points2est* to create three KML map files to display: 1) the sample points, 2) watershed boundaries, and 3) NWI estuarine habitat classification. These KML files can be opened in Google Earth (as well as ArcGIS software).

To use *points2kml*, it is necessary to first run *points2est*.

An example of the *points2kml* tool:

```
points2kml(x = EstData, kmlWS = TRUE, kmlNWI = TRUE,
    IDvar = "Site", FileName = "SamplesFeb2013",
    saveDir = "C:\\MyPath\\EstuaryData")
```

The arguments are:

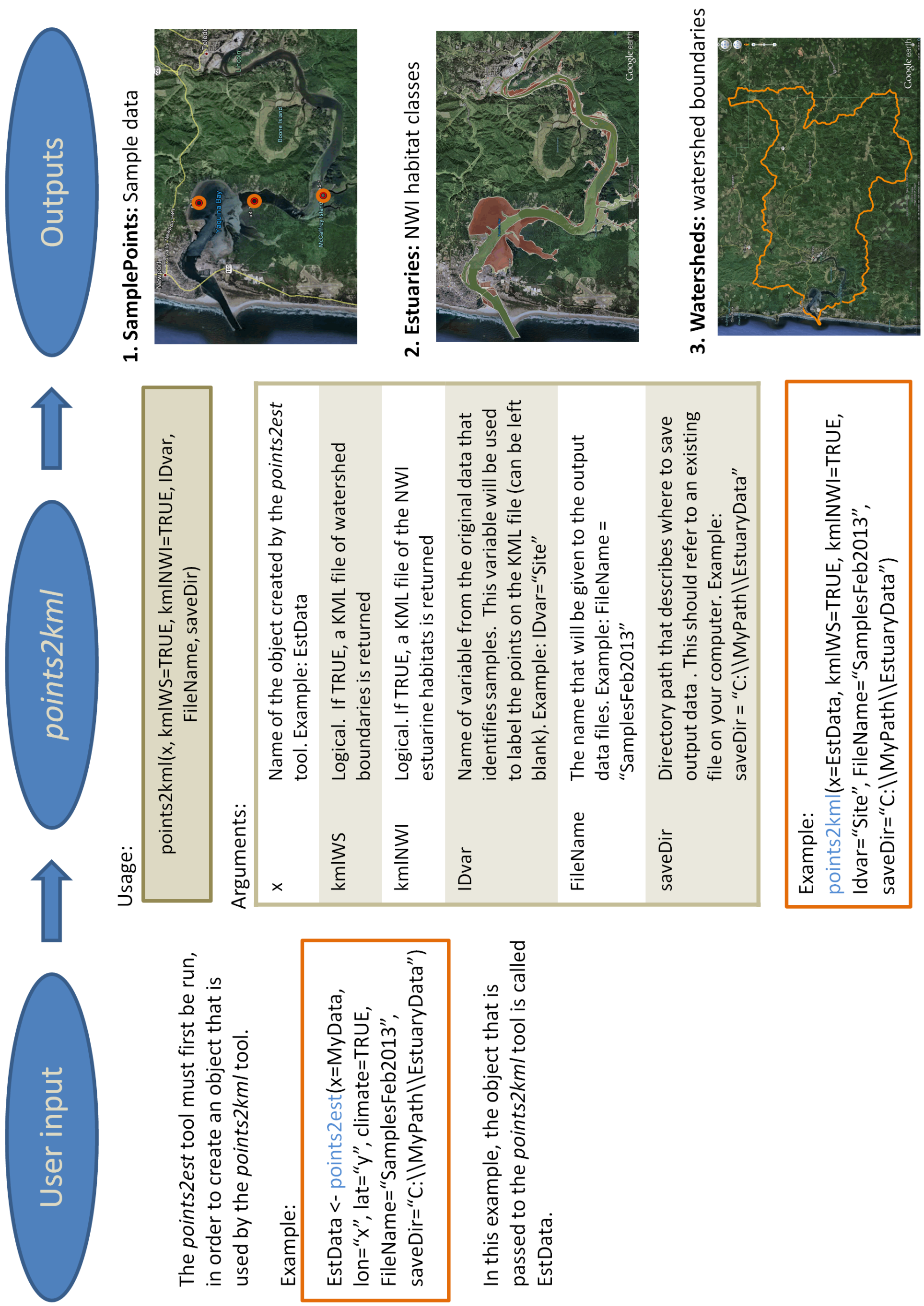
1. x = name of the object created by *points2est* (In STEP4, this was: “EstData”)
2. kmlWS = TRUE/FALSE, if TRUE a watershed KML file will be created
3. kmlNWI = TRUE/FALSE, if TRUE a NWI estuary KML file will be created
4. IDvar = name of variable (i.e., column) in the original data that identifies samples. These data will be used to label the points on the KML file (this can be left blank). Example: IDvar = “Site”
5. FileName = a name for the output data files. Example: FileName = ”SamplesFeb2013”
6. saveDir = directory path describing where to save output maps. Example: saveDir = “C:\\MyPath\\EstuaryData”)

In the above example, *points2kml* generates 3 KML data files that are saved in the directory: ”C:\\MyPath\\EstuaryData”. If Google Earth is installed, you can visualize your data by double clicking on the newly created KML files.

There are a couple known issues with the *points2kml* tool. It can take a very long time if many complex estuaries are being saved to the KML file. In some cases, symbols such as “&” within the original data files may prevent the creation of the KML file. Holes in polygons are not displayed correctly in the KML file (but are otherwise interpreted correctly).

US EPA ARCHIVE DOCUMENT

Figure 14: Description of the *points2kml* tool.



US EPA ARCHIVE DOCUMENT

Leaving R

When you finish working in the R text editor, save the script (File → Save As). You can then reopen the script at a later date and rerun the analysis. When closing R, you will get this message: `Save workspace image? [y/n/c]`. You will probably want to choose the "`n`" option. If the "y" option is chosen, all the R objects (".RData" file) and commands (".Rhistory" file) from your session will be saved to the working directory. I typically find this unnecessary, because the R script preserves the steps for redoing the analyses in a more organized fashion. Option "`c`" cancels the shutdown. If you continue using R, you will eventually want to transition to a text editor, such as RStudio (`http://rstudio.org/`). Text editors designed to work with .R files offer many advantages such as color coding and indenting of code to make it easier to read.

3.5 R terminology

CRAN The Comprehensive R Network: A network of FTP and Web servers around the world that store identical, up-to-date, version of R code and documentation.

Function An object that includes the code needed by R to perform a particular task. Examples include: *mean, source,* and *read.csv.* The *points2est* and *points2kml* tools are functions.

Packages Text files that contain code (i.e., functions) that give R its functionality. For many programs everything is included in the initial installation. R works differently. When you install R on your computer, it includes the program and a set of "base" packages. Every time you open R, these "base" packages are automatically read into R. In addition to these "base" packages, 1000s of additional packages are available from the CRAN website for more specialized operations. These packages are not automatically downloaded with R, but you can download them yourself. For a list of available packages, follow the "Packages" link at `[{http://cr}]an.r-project.org/`.

Working directory The working directory is the location on your computer that R is working from; or in other words, the location where R reads and saves files. The R command for defining the working directory is *setwd.*

US EPA ARCHIVE DOCUMENT

3.6 Error messages

Table 6: Possible errors from the *points2est* and *points2kml*.

Error	Action
data points removed due to missing latitude/longitude	Some sample points did not contain complete location information. You can ignore this error if you are already aware of this issue.
data points appear to be outside the geographic extent, you may want to check this!	Some sample points are located outside the U.S. Pacific Coast. You can ignore this error if you are already aware of this issue.
cannot open file....	The directory pathways are not correct which is preventing data from being accessed or saved. Check the directory pathways. **Check that double back slashes are used to separate folders.**
Longitude coordinates should be negative	The longitude coordinates for the U.S. Pacific coast must be negative.
Longitude/Latitude contains non-numeric data	The longitude/latitude coordinates contain non-numeric characters. These data must be identified and replaced.
No data are located in NWI estuaries	The data are located along the U.S. Pacific coast but not within an estuary. This could occur if data are located along the coast, but not in an estuary. Or, if data fall just outside the NWI estuary boundaries.
KML file is created, but will not display when opened in Google Earth	Some characters in the original user input data may be causing the KML file to break. Note the error line that is reported and open the KML file in a text editor to determine what might be causing the error. Replace this character in the original CSV file. Cut long notes from input file.

US EPA ARCHIVE DOCUMENT

4 Metadata

The following tables describe the variables in the: EstuaryData.csv (Table 8); WatershedData.csv (Table 9); and ClimateMontly.csv data (Table 10).

Table 7: Description of geospatial data files. All spatial data is in projection WGS 84.

Data file	Format	Description
NWI_WA *NWI_OR* *NWI_CA*	polygon SHP files	Estuary habitat delineations based on NWI (U.S. Fish and Wildlife Service 2011). These data including only estuary-related polygons (estuarine, marine, and tidal river). A unique watershed identifier was added to each NWI habitat polygon to identify polygons in the same estuary.
Watershed	polygon SHP and KML file	Watershed delineations for US Pacific Coast estuaries and coastal drainage areas (Lee and Brown 2009). Each watershed polygon has a unique identifier. There is a 1-1 correspondence between most watersheds and estuaries. However, a few watersheds include more than one estuary due to recent updates of the NWI. These watersheds/estuaries are identified in the database. **Note:** Humboldt is composed of two watersheds (P130x02 N, "Arcata Bay"; P130x01 S, "Humboldt Bay"). San Francisco is composed of two watersheds (P090a N; P090w S).
EstMouths	point SHP and KML file	Point locations near the estuary mouth midpoints. NOTE: Estuaries are dynamic and unjettied estuary mouths can and do move.
NOAAsalinity	polygon SHP and KML file	NOAA salinity zones for 36 U.S. Pacific coast estuaries (plus some bays): **tidal fresh zone** = 0.0-0.5 ppt **mixing zone** = 0.5 to 25 ppt **seawater zone** = >25 ppt If data are unavailable, NA values are returned.

US EPA ARCHIVE DOCUMENT

Table 8: Description of estuary data variables (EstuaryData.csv). For more information see section 2.1.

Variable name	Description	Origin
wsID	Unique ID of watershed where estuary is located	Modified from Lee and Brown (2009)
estName	Name of estuary	Modified from Lee and Brown (2009)
estState	State of estuary location (WA, CA, OR)	Based on comparisons of NWI estuary polygons with state boundaries in Google Earth
estLongitude	Longitudinal coordinate of estuary mouthpoint (decimal degrees)	Midpoint of estuarine mouthpoint estimated from Google Earth
estLatitude	Latitudinal coordinate of estuary mouthpoint (decimal degrees)	Midpoint of estuarine mouthpoint estimated from Google Earth
estArea	Total area (m^2) of estuarine habitat within each watershed. Typically, a watershed includes only one estuary. However for a few smaller estuaries, more than one estuary is located within a watershed due to recent revisions of the NWI. In these cases, estArea is not provided. Watersheds with more than one estuary can be identified by the estCount variable in the WatershedData.csv data; estuaries with a wsID that corresponds to watersheds with estCount >1 share the watershed with other estuaries.	Calculated from NWI geospatial data
subtidalArea	Total area (m^2) of subtidal (E1) NWI polygons within an estuary	Calculated from NWI geospatial data
intertidalArea	Total area (m^2) of intertidal (E2) NWI polygons within an estuary	Calculated from NWI geospatial data
marineArea	Total area (m^2) of marine (M2) NWI polygons within an estuary. Typically, marine habitats were not included in estuarine area. However, they were included in a few cases, such as in some bays. Decision to include M2 areas were based on best professional judgment and data availability.	Calculated from NWI geospatial data
riverArea	Total area (m^2) of tidal influenced river (R1) NWI polygons within an estuary	Calculated from NWI geospatial data
estNotes	Comments related to data	

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Table 9: Description of watershed data (WatershedData.csv). For more information, see section 2.2.

Variable Name	Description	Origin
wsID	Unique watershed identifier	Modified from Lee and Brown (2009)
wsType	Describes relationship between watersheds and estuaries (Fig. 6): **EDA** Estuarine Drainage Area. Watershed delineation was defined by an estuary. **CDA** Coastal Drainage Area. These typically contain no estuary; however, in some cases, they may include one or more estuaries due to revision of NWI after watersheds were delineated. This is not an issue for larger estuaries.	Based on comparisons of watershed and estuary SHP files
estCount	Number of estuaries in the watershed. Typically CDAs will have no estuaries and EDAs will have 1 estuary. However, this is not always the case due to the recent update of the NWI.	Modified from Lee and Brown (2009)
wsArea	Area of watershed (m^2)	Calculated from geospatial data
wsNotes	Comments related to data	

US EPA ARCHIVE DOCUMENT

Table 10: Description of climate data. For more information, see Section 2.4.

Variable name	Description	Origin
wsID	Unique watershed identifier	Modified from Lee and Brown (2009)
month	Month of temperature data (Jan-Dec)	
Watershed climate data		
wsPPT	Monthly average of cumulative precipitation (mm) averaged over the watershed area.	PRISM (Daly et al. 2007) monthly climate data averaged from 1971-2000 at resolution 30-arcsec, or 800m
wsTair_min	Monthly average of minimum daily temperature (°C) averaged over the watershed area	
wsTair_max	Monthly average of maximum daily temperature (°C) averaged over the watershed area	
wsTair_avg	Average of monthly minimum and maximum temperature (°C) and then averaged over the watershed area (as described in FAQ of PRISM website)	
Estuary climate data		
estTair_ min	Monthly average of daily minimum air temperatures (°C) near estuary mouth	Daymet (Thornton 2009) daily climate data from 1980 to 2003 at resolution of 1 km Daymet
estTair_max	Monthly average of daily maximum air temperatures (°C) near estuary mouth	
estTair_avg	Monthly average of daily average air temperature (°C) near estuary mouth	
estSST	Monthly sea surface temperatures (SST, °C) averaged over a 28 year period (1982-2009; 1981 was excluded because it did not include the entire year) within 10 km of the estuary mouth	Monthly sea surface temperature data averaged over a 28+ year period (1981-2009) from AVHRR satellite based remote sensing observations at 4 km resolution and within 20 km of shoreline (Payne et al. 2011)

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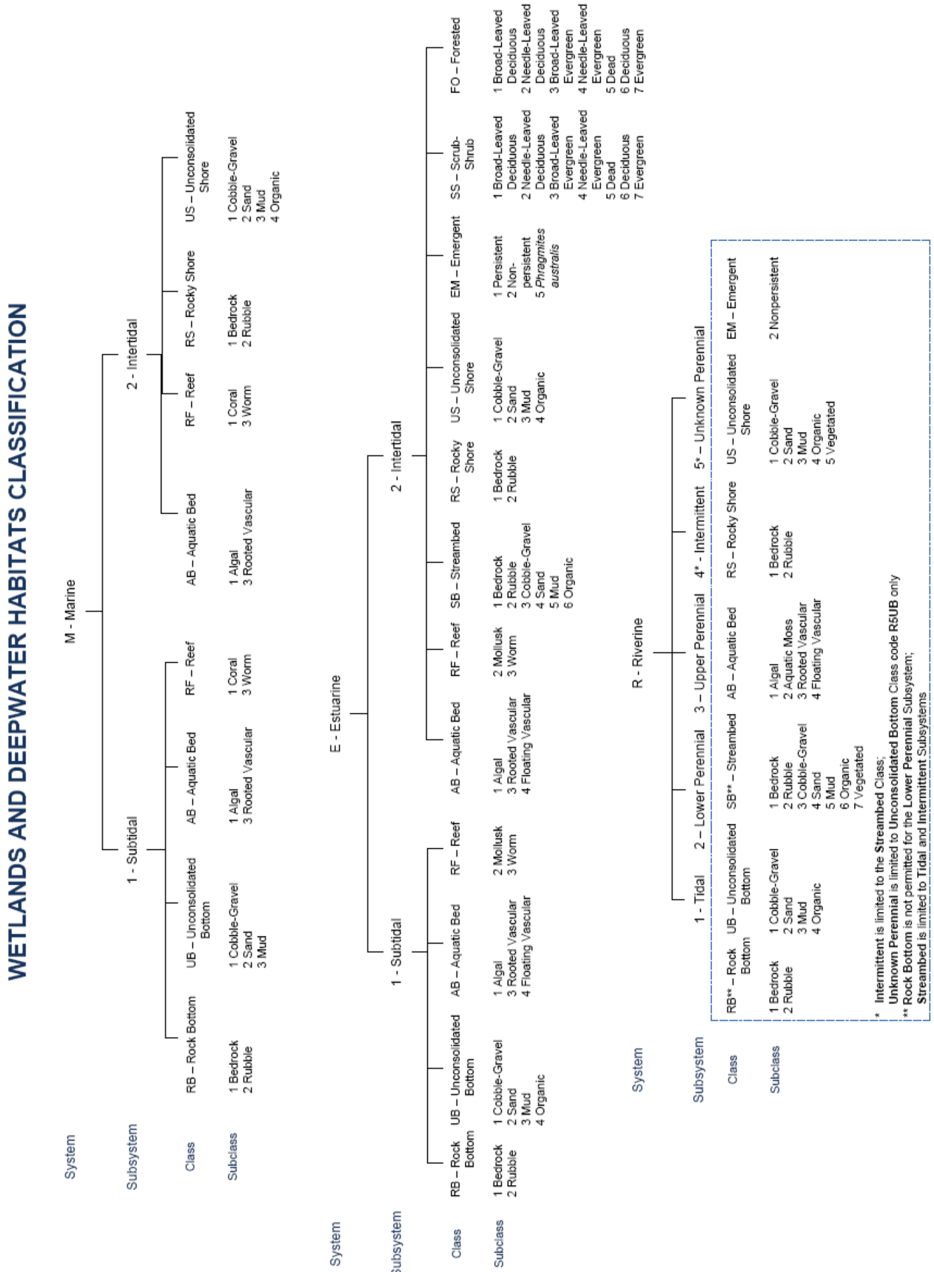
Appendix A

National Wetlands Inventory wetlands and deepwater habitats hierarchical classification system.



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Appendix B

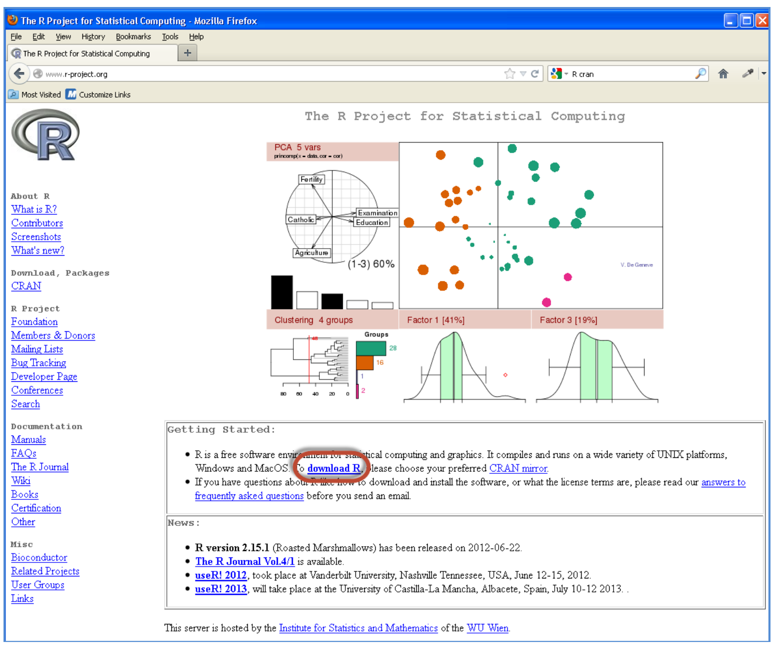
R Installation and Setup[1]

Installing R is very easy, regardless of your operating system.

- Go to `www.r-project.org`, where you'll see the R homepage (Fig B.1).
- Click on download R, which will take you to the "CRAN mirrors" page.

CRAN refers to the "Comprehensive R Archive Network". This is simply a bunch of computers scattered around the world that keep exact duplicates of all the files associated with R. Select a mirror that is geographically close to you – this is good for both the servers (reduced load) and the users (reduced download times). You will do this again when you install packages.

Figure B.1: R project homepage



- After selecting a mirror, a download window will appear (Fig. B.2), which will look the same regardless of the mirror you choose.

[1]From Michael Dillon's website: `http://www.uwyo.edu/mdillon/HoR.html`

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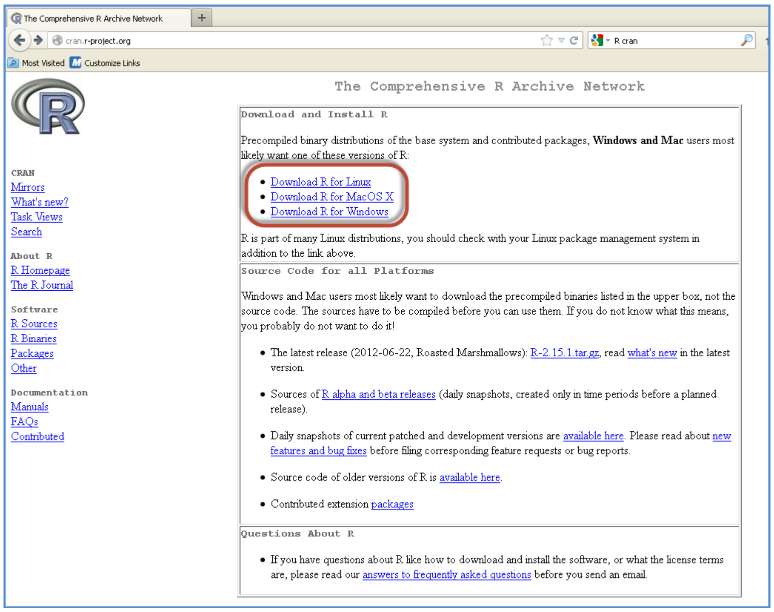
- Choose the link for your operating system from the Download and Install R box at the top. (Source code needs to be compiled, which is probably not something you are interested in doing).

For Windows, choose the base link, then Download R X.XX.X for Windows and double-click the file to install.

Figure B.2: Download R for your operating system from a CRAN mirror.



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