USE OF THE GENERIC MAPPING TOOLS PROGRAM TO PLOT ARGOS TRACKING DATA FOR SEA TURTLES

Denise M. Ellis [1] and George H. Balazs[2]

[1]Joint Institute for Marine and Atmospheric Research, 2570 Dole Street, Honolulu, Hawaii 96822-2396, U.S.A.
[2]National Marine Fisheries Service, Southwest Fisheries Science Center, Honolulu Laboratory, 2570 Dole Street, Honolulu, HI 96822-2396, U.S.A.

Satellite telemetry is used to track the movements of sea turtles and other animals worldwide. One challenge a scientist faces is how to present the numerical data received from transmitters as a publication-quality graphic. Presented here is one way to convert tracking data into such a format using a powerful system called the Generic Mapping Tools (GMT) program, created by Paul Wessel and Walter H. F. Smith. Many GIS integrated systems, such as Argos' ELSA, and ARC/INFO or MapInfo, are available, but can range upwards of US$4500 for the initial purchase. High resolution maps of locations worldwide can be created relatively easily using GMT, a free, public-domain collection of over 50 tools that run on UNIX, an operating system similar to DOS (Wessel and Smith, 1991; Smith and Wessel, 1990). GMT uses the WGS-84 ellipsoid as its default global projection and can be customized with personal preferences through the .gmtdefaults file. More information about GMT can be obtained over the Internet at: http://www.soest.hawaii.edu/wessel/gmt.html or by writing to: GMT c/o Paul Wessel, SOEST, 2525 Correa Road, Honolulu, Hawaii 96822 U.S.A. (Wessel and Smith, 1995).

The first step in making a map, such as shown in Fig. 1, is to create an executable ASCII file containing all the required command lines as follows: #!/bin/sh, where the pound sign (#) is used to "comment out" or exclude from execution that particular line, and simply notes 'this is a shell script.' The line, PSFILE=<filename>.ps, indicates the PostScript file where the output of all commands will be compiled. The map scale is created with: SCALE=X/Yd, where X and Y are the number of centimeters per degree for the corresponding axis; here, both the x and y-axes are 1.57 cm per degree. The line: gmtset DEGREE_FORMAT 3, sets the labeling so longitudes are displayed as 0 to 180 and latitudes as 0 to 90 degrees with the letters W, E, S and N appended as appropriate. Four basic commands are then used to create a map as follows:

1) psbasemap. This program creates a basic map frame for a selected area. A base map was created using the command, -R177/192.2/-21/-13, where each number specifies a corner (W/E/S/N). Map projection with the previously designated SCALE (20 available including Mercator, Hammer, etc.) was selected with the command, -Jx${SCALE}, where x specifies a linear projection. The position of the map was set at 2.5 cm from the left margin (-X2.5) and 3.8 cm from the bottom edge (-Y3.8). The tickmarks and their labels are situated every 5 degrees on the left and bottom of the frame by the command, -B5/5WeSn. For tick marks on the right and top of the frame, the 'e' and 'n' would be capitalized. The command, -K, allows you to append additional commands to the PostScript file. The line, > $PSFILE (or >> $PSFILE), at the end of each command line sends the results to the named PSFILE.

2) pscoast. This program includes land and water masses on the basic map. Each mass can be shaded (0-255, where 0 is black and 255 is white), colored (red/green/blue, where 0-255 provides intensity), or textured. The -G command sets the 'painting' for 'dry' areas with black as the default, -G155/240/90, colors land masses green. The -S command sets the 'painting' for 'wet' areas with white as the default, -S100/255/255 colors the water blue. GMT draws coastlines, rivers, and political boundaries with different commands. Coastlines were included as a black line with a pen size of 3 with the command, -W3/0/0/0. There are five resolutions (-D) of which the intermediate resolution (-Di) thats plots polygons greater than 20 km2, is probably sufficient for most maps or high resolution (-Dh, features > 1 km2) could be used. The -O command overlays output from this command line onto the previous map. Note -R and -J are not appended as no changes were made.

3) psxy. This program includes the database latitude and longitude files that were created and displays them as lines or symbols. Longitude values should be entered as 0 to 359.999. Latitude values should be entered as 0 to 90, positive in the northern hemisphere and negative in the southern hemisphere. Data files will be read into GMT as X, Y pairs (longitude, latitude). The command, -:, allows the data to be read as Y, X pairs (latitude, longitude). Database files for each turtle were inputted twice, once to create tracklines and the second time to create symbols. Various types of lines (-W) and symbols (-S) can be created. Here, three lines with a pen size of six were created. The command, -W6/255/0/255, created a solid, hot pink line, -W6/255/50/50ta, an orange, dashed line, and -W6to, a black, dotted line. Three black symbols were created by -Si0.15, an inverted triangle with a side length of 0.15 cm, -Ss0.13, a square with a side length of 0.13 cm, and -Sc0.15, a circle with a diameter of 0.15 cm. Again -R and -J are not appended and -O indicates commands are overlaid.

4) pstext. This program positions text such as labels, titles, and other text onto the map. Seven fields of information are needed to create the text: X, Y, size, angle, fontno, justify, and text. X and Y can be either longitude, latitude data, or x, y values in cm (position of text is relative to map position). The 'fontno' field contains the number for a particular font, the default, 0, is Helvetica. The 'justify' field indicates the part of text on the x, y position. Text files can be included with the command line or as a separate file. The positioning for the base map (-R) of the second pstext was changed to cm (-R0/27.9/0/21.6) from latitude, longitude and the scale was set at 1:1 (-Jx1). The command line, 7.62 7.62 12 00 1 25693, placed "25693" as a 12 point, Helvetica string at 0 angle, and justified on the lower left corner (1) of text 10.2 cm from the left margin and 11.4 cm from the bottom. No -K command was included in the last command line, which indicates the map is finished to GMT.
The final product is obtained by executing the program in UNIX and printing the output file on a PostScript compatible printer (Fig. 1, a black and white version). A high quality graphic is the reward for the time expended modifying the programs and is an excellent complement to manuscripts and presentations.

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EXAMPLE OF A GMT COMMAND FILE

```
#!/bin/sh
PSFILE=Samoa_Fiji.ps
SCALE=1.57/1.57d
gmtset DEGREE_FORMAT 3
psbasemap -R177/192.2/-21/-13 -Jx${SCALE} -X2.5 -Y3.8 -B5/5WeSn -K > $PSFILE
pscoast -R  -Jx  -Di -G155/240/90 -S100/255/255 -W3/0/0/0 -O -K >> $PSFILE
psxy 25692_96.dat -Jx  -R  -W6/255/0/255 -O  -K  -: >> $PSFILE psxy 25694_96.dat -Jx  -R  -W6/255/50/50ta  -O
-K  -: >> $PSFILE psxy 25693_96.dat -Jx  -R  -W6to  -O  -K  -: >> $PSFILE
psxy 25693_96.dat -Jx  -R  -Si0.15 -G0 -O  -K  -: >> $PSFILE psxy 25694_96.dat -Jx  -R  -Ss0.13 -G0 -O -K -: >>
$PSFILE psxy 25692_96.dat -Jx  -R  -Sc0.15 -G0 -O -K -: >> $PSFILE
pstext -R177/192.2/-21/-13 -Jx  -O -K <<END>> $PSFILE
191.400 -14.000 12 0 0 1 Rose
191.400 -14.300 12 0 0 1 Atoll
178.500 -16.000 12 0 0 2 Fiji Islands
187.000 -13.300 12 0 0 1 W. Samoa
END
pstext -R0/27.9/0/21.6 -Jx1 -O <<@END>> $PSFILE
7.62 7.62 12 0 0 1 25693
7.62 5.84 12 0 0 1 25692
7.62 2.54 12 0 0 1 25694
20.62 2.41 12 0 0 1 Niue
0.5 13.97 16 0 0 1 Post-nesting Migrations of Green Turtles from Rose Atoll, American Samoa to Fiji, 1995-96
@END
```

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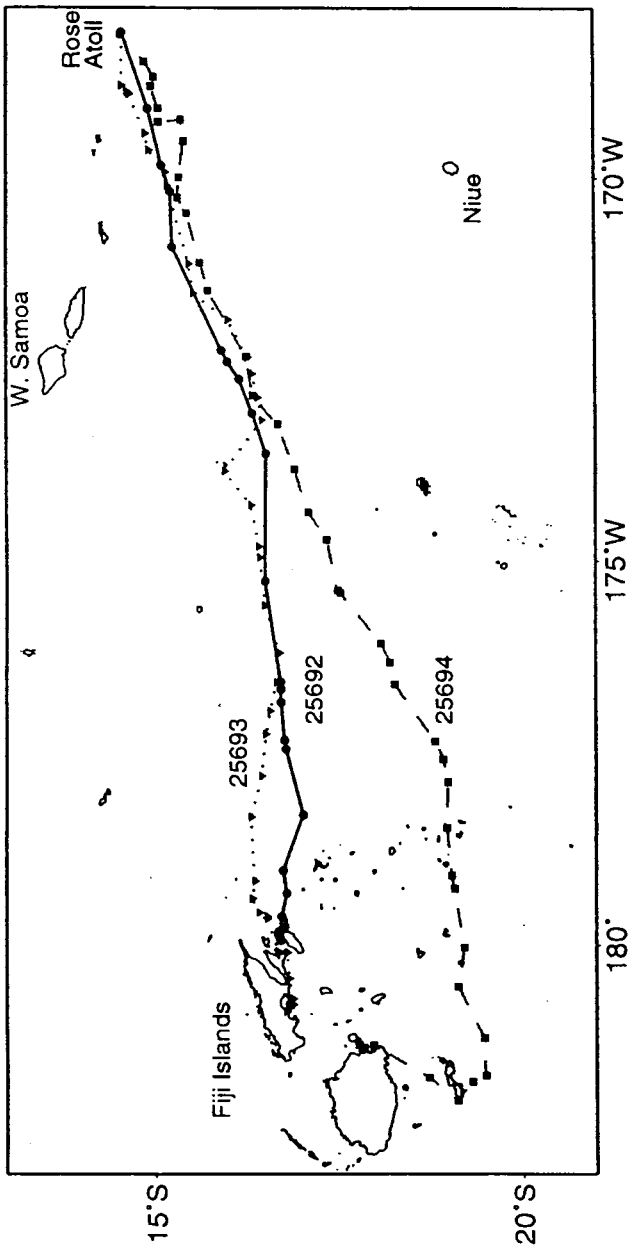

Figure 1. Graphic produced using the Generic Mapping Tools Program showing post-nesting migrations of three green turtles from Rose Atoll, American Samoa to Fiji, 1995-96