# AquaTracker

Program Version 2.40

Programmed and developed by José J. Reyes-Tomassini
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In association with the **Puget Sound Telemetry Workgroup**[2]

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[2] *A cooperative work group consisting of users of acoustic telemetry tags and operators of acoustic arrays in and around the Puget Sound region*

## A brief note from the author

I am sure that you can't wait to load your data up and begin playing with the program. This manual should help you do just that! But before we begin, let's take the time to acknowledge the people and organizations involved in the creation of this software.

*AquaTracker* came into existence as I was trying to help Megan Moore, also at NOAA Manchester, work on the telemetry data from the Hood Canal Steelhead Supplementation Project. During that time we had many productive brainstorming sessions in which we established the data import format, the program limits, and the visual feel of the program.

I could not have created this program without the guidance, and full support of my supervisor and lead of our Behavioral Ecology Team here at NOAA Manchester Research Station, Dr. Barry Berejikian. He is also pushed forward to make this tool available to a wider audience.

I would also like to thank a number of contributors, who helped conceive some of the tools provided in this program, whether by asking for a tool, suggesting one outright or providing good feedback on it: astronomical calculator and diel histograms (Frederick Goetz, Army Corps of Engineering); receiver residence and frame capture (Joe Smith, U. Washington); versatile animation (Ashley Melancon, LSU); heat maps (Andy Jasonowicz, U. Washington); detection plots (Jon Lee, NOAA) and land-avoidance (Jessica Rhodes, U. Washington).

Like many biologist-programmers, I am a self-taught programmer. AquaTracker is the first application I have ever written for a wide audience. It is my hope the program provides you with the power needed to reduce, organize, and analyze, acoustic telemetry data, and that good science and a better understanding of your data comes from its use.

# Contents

# AquaTracker Primer

## The story of AquaTracker

**AquaTracker** was created as a software tool to visualize telemetry data and to quantify fish behavior based on this data. We gathered input from users of acoustic telemetry technology and put together a package of tools based on their ideas and suggestions.

The first release (version 0.4A) was very limited in its analytic capabilities; still it included many useful features. This early version was used by some members of our *ad hoc* telemetry workgroup for a number of presentations at AFS 2012 and was used to analyze data published by us in a manuscript in the journal PloS ONE.

Since then, many tools have been added and perfected, bugs have been squashed (fixed), and the program has been thoroughly revised and optimized. The list of users has now expanded to include scientist in Massachusetts, California, Louisiana and other states.

## Program speed and other considerations

**AquaTracker** was written entirely in Visual Basic and compiled directly to an executable file, with all compiler switches set to optimize speed. Advanced programming techniques and software optimization were used throughout in order to enhance data processing speed and track rendering so as to deliver a usable package that can handle large sets of data. The bottleneck for data processing in **AquaTracker** is (usually) the loading of the data set itself. We tested the program on a modern day computer, running Windows 7, by loading a data set of 220,000 detections. The program was able to load and plot the data in 8.7 seconds[1]. Our smaller data sets, consisting of 5,000 detections or less, are loaded up by AquaTracker at much faster rates, usually less than 2 seconds. A new native format featured in version 2.4 (**AQN**), allows loading files even faster: <u>the 220,000 detection file mentioned above now takes 5.2 seconds to load[1]</u>. Thus, the new AQN file format loads about 40% faster than the CSV unformatted file.

[1]On a 3.16GHz Core 2 Duo (E8500) PC with 3GB RAM, running 64-bit Windows 7 Professional Edition.

## List of standard program features

✓Display a track string showing the name of the receivers visited by a fish
✓Explore the detections generated by a single receiver
✓Show the detection density for each receiver in an array
✓Group receivers by geographic proximity
✓Automatically detect if the detection radius of two receivers overlap
✓Detect the arrival of fish in pairs or groups to a receiver or groups of receivers
✓Show if fish moved during the day, night, or twilight
✓Calculate fish track statistics and parameters of movement (e.g. Linearity and Distance Traveled)

## New features in AquaTracker 2.40

Bug fixes for the new version are outlined in the **Built_Notes.pdf** file located in the main folder of the application package. There are over 100+ bug fixes in this version, dozens of improvements and many new features. Here is a short list of some of the new features:

✓Native file support (file type *AQN*)
✓Unified data loader with integrated converter and importer
✓New color schemes for heat-maps
✓Random walks with persistence parameter
✓Auto-detection of *land-locked* receivers for land-avoidance
✓Calculation of *oceanographic distance*
✓Verbose stamp description/Stamp explorer
✓New interactive feature in scatter plots, allows highlighting of receivers
✓Singleton stamps can be automatically detected and deleted
✓Extensive integration of the zoom map feature into the rest of the program

## Installing the program: New users

To install **AquaTracker**, simply run SETUP.EXE on the main folder in the installation package and follow all prompts.

## Upgrading from earlier versions

Download and copy the .EXE file into your AquaTracker application folder. Delete your AquaTracker.EXE file in the folder and rename the file you just downloaded as AQUATRACKER.EXE. If an error occurs, or if you have a very early version, you may need to install the full application package and delete your old version.

## What you will need to get started

You will need a CSV file containing the "pings" generated by the receivers (the file may or may not contain the deployment information too). You can import almost any file into AquaTracker as long as it follows some simple rules. You can import mobile tracking data into AquaTracker, although some of the analysis tools won't work properly with mobile tracking data, you should be able to plot the data and perform some basic analysis.

**A map that contains at least two geo-referencing control points is needed to visualize the movement of the fish in relation to the physical and hydrological barriers that the fish encounters. However, a map is not necessary for the analysis or visualization of your data.**

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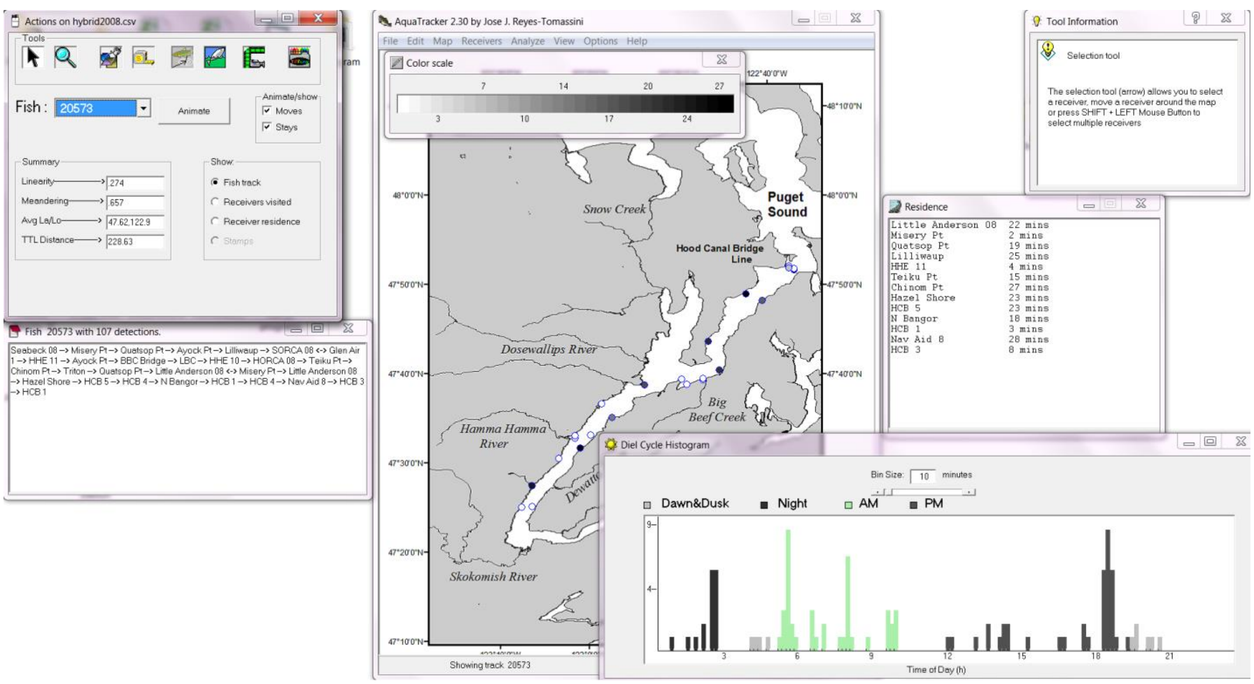
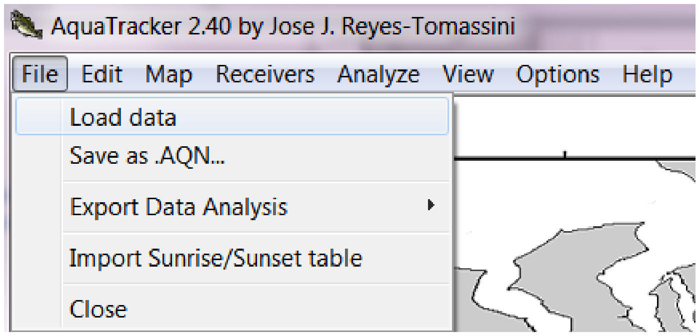
# Chapter 1: Importing Data and Maps

The first step in using ***AquaTracker*** to analyze your data is importing it into the program. Generally speaking, your data consist of the information gathered by the acoustic receivers. You can import up to two million detections into the program, as long as the data is formatted properly (To learn more about program limits see Appendix B: Program Limits). **In this chapter you will learn how to import detections into the program and how the data should be formatted.** Additionally, you will learn how to load a map and how to geo-reference the map. The map itself also contains information which ***AquaTracker*** uses to expand its ability to analyze your data.

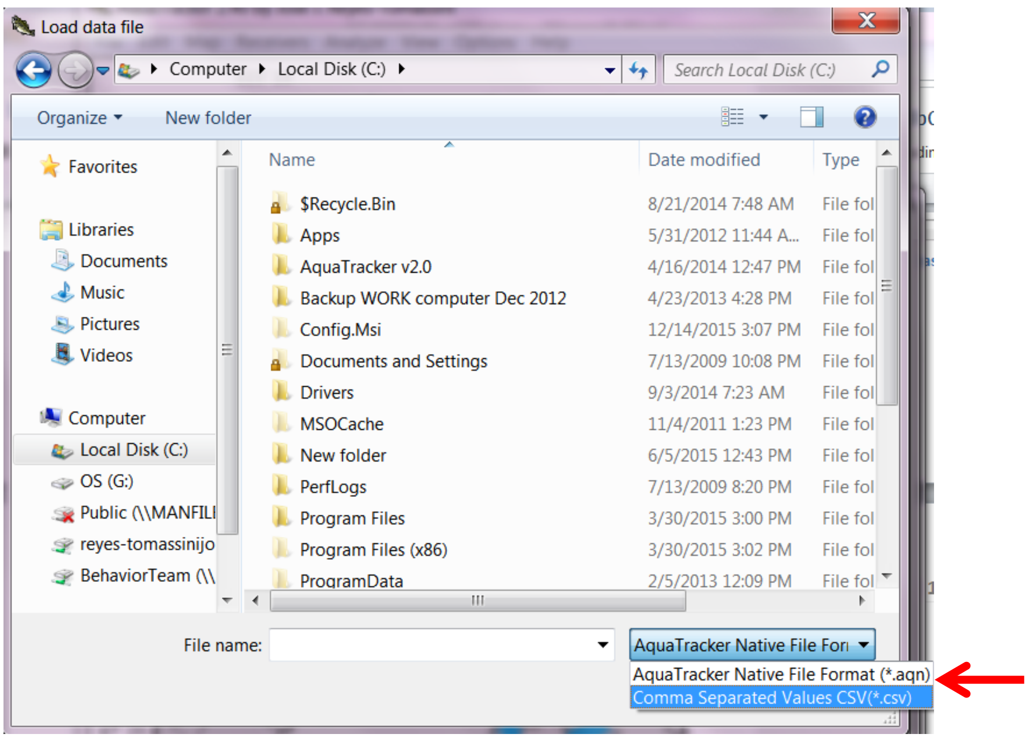



**AquaTracker various windows show information about the track being displayed and the tool selected. The program has many tools which when combined in different ways can result in visualizing different aspects of the data.**

# 1.1 Importing Track Data




To import a CSV file, first go to **File→Load data**. The program will display its **Load data file** window, as shown below.




Choose the CSV format from the file type list, as shown by the arrow above. <u>The program will only allow you to choose from a file name with the extension **CSV**</u>. If the file does not have a header with tags, the program will ask you if it's OK to run the Converter (see 1.2 Using the *Converter* application).

**After you load a data file, all the tracks in the file are displayed simultaneously in the main window and you will also see the Actions window appear on the left of the main program window.**

## The format of the imported file

**AquaTracker** accepts comma-separated values files (CSV) detection files, which can be created in any spreadsheet program by using the SAVE AS… function. Because the *delimeter* in CSV files is a comma, the character is a *reserved* character and may not be used elsewhere in the file. Thus, **names of receivers should not contain commas**, as this will cause the file to be misread.

When importing any file, keep in mind the following about how the program expects the data to look like:

1) The fish code identifier can only be in decimal or hexadecimal. If the identifier is in hexadecimal, it needs to begin with the characters "&H". Fish names such as "Fabio" or "Nemo" are not legal fish identifiers.
2) No two fish should have the same number/code
3) Likewise, no two receivers should have the same name/ID
4) No blank detections (incomplete stamps). Blank stamps or stamps with a 0 on either latitude or longitude will be **rejected** and ignored. Rejected stamps will be found in a file created during import called *[Name of imported file]* __Rejected.csv.
5) All detections occur in the same hemisphere
6) Latitude/Longitude for a receiver does not change throughout the file
7) As mentioned above, no commas are allowed in any receiver name or fish code

If you think your data does not follow these simple rules, you should try to use the *Converter* program (***Converter.exe*** in the installation package). The converter program will take care of most of these issues (except #5 and #7, as they are hard-coded into the program).

### Old import format (Version 0.3A or earlier)

Earlier versions of the software used the following format, which is still supported by the current version. This format is a fixed-order format. Columns must be in the expected order or the program will not load the data properly.

Row 1: A single header row containing the header for each column.
Row 2: Start of the data. The format is as follows:

| **Column A** | **Column B** | **Column C** | **Column D** | **Column E** | **Column F** |
|---|---|---|---|---|---|
| Fish Acoustic Tag Code (decimal or hexadecimal) | Name of Receiver where CODE was detected | The date stamp which is formatted as DATE TIME (UTC) | A general string used to identify experimental groups. This information is appended to the fish, not the | Latitude (in decimal degrees) | Longitude (in decimal degrees) |

| | | | | | |
|---|---|---|---|---|---|
| | | | receiver. | | |

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Code | Site | Expr1 | General_I | Latitude | Longitude |
| 2 | 20584 | Ayock Pt | 5/29/2008 12:35 | SKOK | 47.5103 | 123.06 |
| 3 | 20584 | Ayock Pt | 5/29/2008 12:38 | SKOK | 47.5103 | 123.06 |

A sample file in this format, **Sample.CSV**, is included in the sample folder in the application package. Above is a screen capture showing how this file looks in a spreadsheet.

## New import format (*Version 0.4A or higher*)

In the new file format, the header has a case-insensitive **column tag** on each column to be imported. This allows the order of the columns to be user-defined. The following are valid tags:

| | |
|---|---|
| **[Fish_Code]** | Unique numerical code from acoustic tag. This field can be hexadecimal |
| **[Receiver_Name]** | Receiver name or site name |
| **[Date/Time]** | Date-time field exported by VEMCO™ analysis software |
| **[Date]** | Date of detection |
| **[Time]** | Time of detection |
| **[Group]** | Group (i.e Control or Experimental, release site, etc.) |
| **[Lat]** | Receiver's latitude position |
| **[Long]** | Receiver's longitude position |
| **[Tag]** | OPTIONAL: Tag for receiver, used for analyzing receivers by tag group (see section **Error! Not a valid result for table.**) |

Except for [Tag], which is optional, each of these valid tags and the time stamp (either [Date] and [Time] or [Date/Time]) has to be included in your first row. Otherwise, the program will not be able to properly import the file. If your data is not grouped by treatment, write a Group with the top row labeled by the tag [GROUP] but leave the rest of the column blank. Below is what the file should look like in a spreadsheet. Remember: the order of the columns is not important, as long as the tags are present!

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | [Receiver_Name] | [Date/Time] | [Group] | [Lat] | [Long] | [Fish_Code] |
| 2 | HCB 3 | 6/16/2008 11:35 | SKOK | 47.8619 | 122.63 | 20584 |
| 3 | HCB 3 | 6/16/2008 12:46 | SKOK | 47.8619 | 122.63 | 20584 |
| 4 | HCB 2 | 6/16/2008 5:57 | SKOK | 47.8639 | 122.63 | 20584 |
| 5 | HCB 2 | 6/16/2008 5:58 | SKOK | 47.8639 | 122.63 | 20584 |
| 6 | HCB 2 | 6/16/2008 5:59 | SKOK | 47.8639 | 122.63 | 20584 |

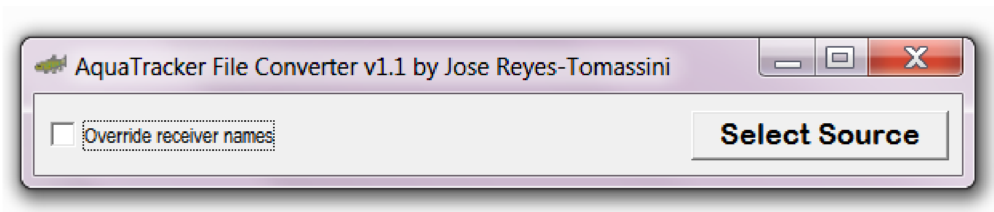
A sample file in this format, **NewFormat_Sample.CSV**, is included in the sample folder in the application package.

## 1.2 Using the *Converter* application

An application called *CONVERTER* is included with the AquaTracker 2.4 installation package. The converter application is an easy to use program that allows you to import data in a variety of formats. The *CONVERTER* application automatically creates a CSV AquaTracker-ready import file.


**If AquaTracker detects an unsupported CSV file, it will automatically run the Converter application, rename the CSV file to "converted__XXX.CSV" and load the converted file.**

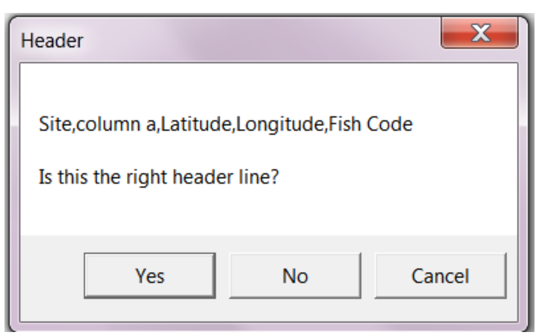
You can run the converter as a stand-alone application. When started outside of AquaTracker, Converter will greet you with the following window:



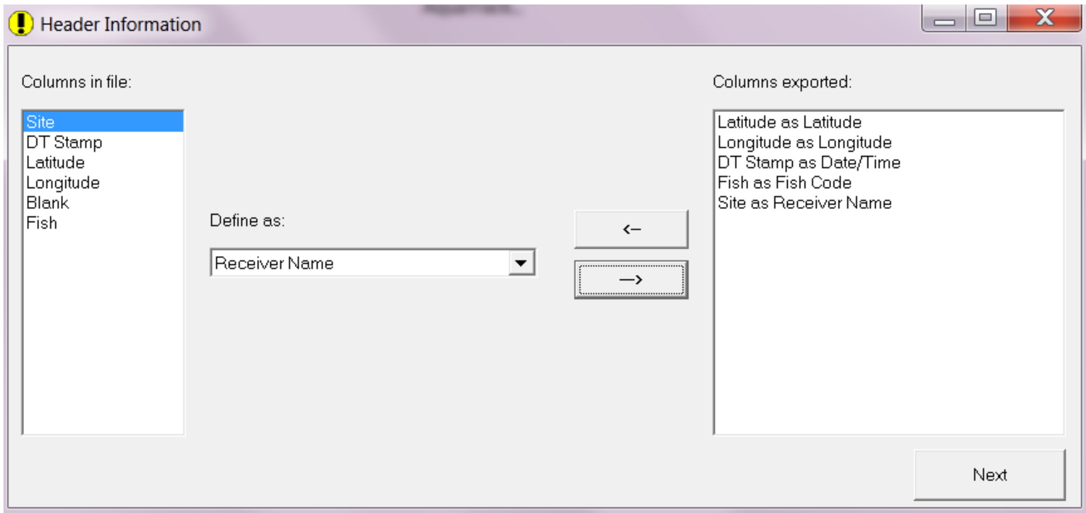

Click on **Select Source** to choose the file to convert. The program will automatically attempt to open a path to the source directory and create a destination file named "Converted_XXXX.CSV", where "XXXX" is the name of the source file. If the source directory is read-only, the program will prompt you to choose a directory and filename to save the converted data.

Notice the checkbox **Override receiver names**. You want to check this box for sure if you have data that requires the program to name the receivers (e.g. for mobile detections). For more on this see Auto-naming of receivers.

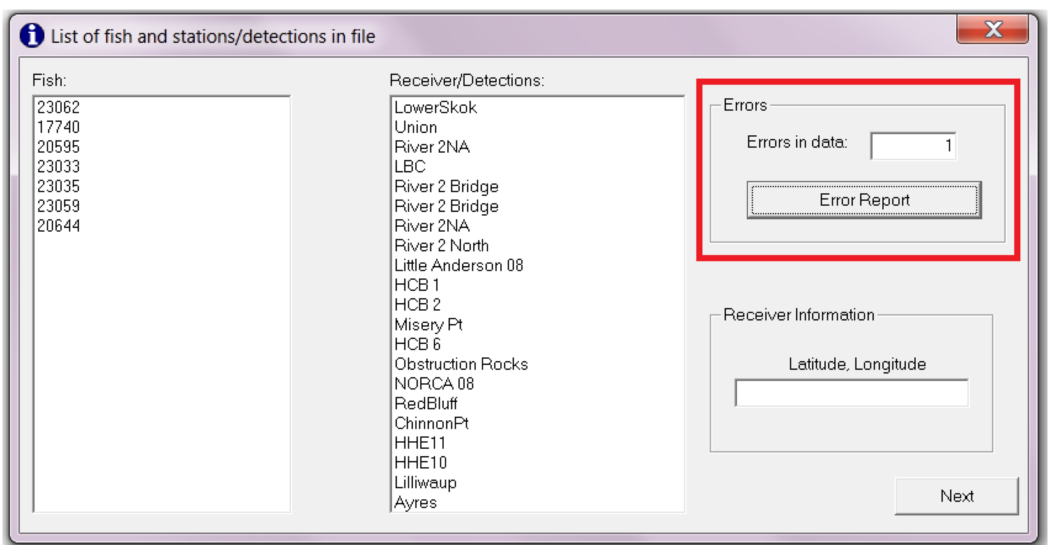
After choosing a source file and (if needed) a destination file, Converter will prompt you to verify that the first row in the file is the header row. Click **YES** if the right header is showing up or click **NO** if the header is farther down in the file (e.g its on a later row). If a header does not exist, you will need to click **CANCEL**.



The program will use this header to label the columns in the following rows. In the example above, “column a” is simply the date/time column but all the other columns contain the information described by the header. The converter program will recognize the names of some of the columns an automatically populate the next window.




To define a new column from the file, select the column in the file and choose a definition from the pull-down list. Click on the → arrow to make it an exported column. To deselect any defined column, click on the ←arrow. Click **NEXT** when you are done with defining the columns.




The next window shows all the receivers, fish codes, and coordinates in the file. <u>You can **delete a receiver** or **change its name** by clicking on the receiver on the list</u>.

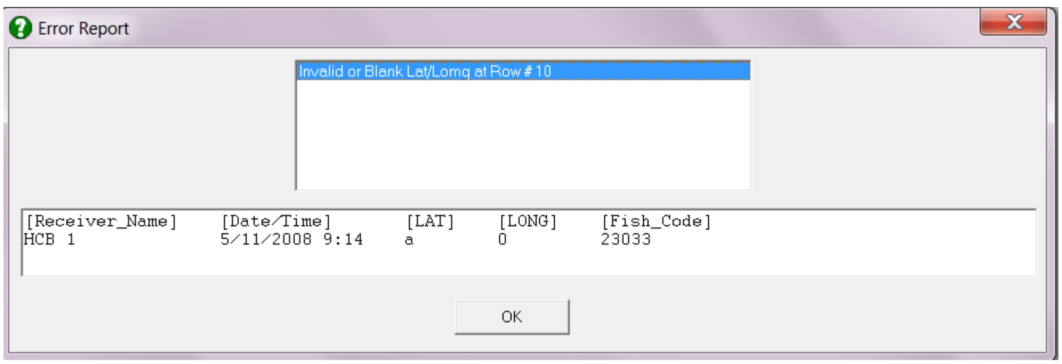
**To delete the receiver**, click on the receiver on the list and the program will ask if you would like to exclude this receiver from the export. Any detections associated with this receiver will not be included.

To **change the name of the receiver**, click on the receiver in the list and answer NO to the next window (asking if you want to exclude it). The program will now give you the option to rename the receiver instead.

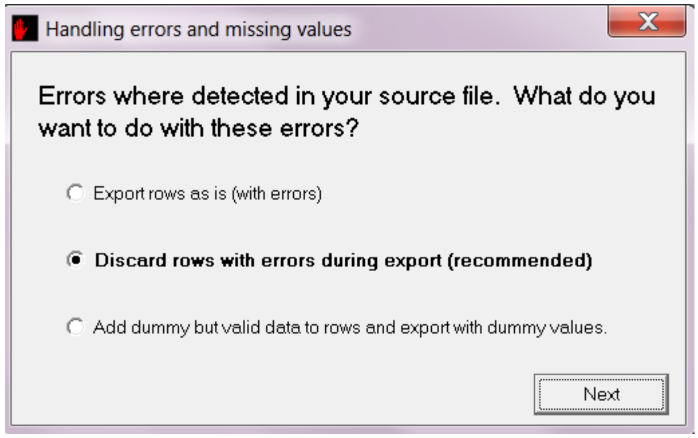
You can also **change the coordinates** for the receiver by entering them in the text box provided. This will override the values in the file.

If the program has found an error at this point, it will display it on the Error section of the window. Click on **Error Report** to see what is causing the error.

If you open the error report, you will need to click on the error to see more information about it, as seen below.




Here the error was caused by the word "a" on the column labeled LAT, where the program expects a number. The error report indicates this error was found on the 10$^{th}$ data row, so you could quit the program and manually fix this error in the file or wait for the program to give you an opportunity to ignore the row or put dummy/previous information in this row. Once you have reviewed the report, quit the **Error Report** window and click **NEXT** on the main program window.




Because an error was found during processing, the program needs to know what to do with the error. There are 3 options:

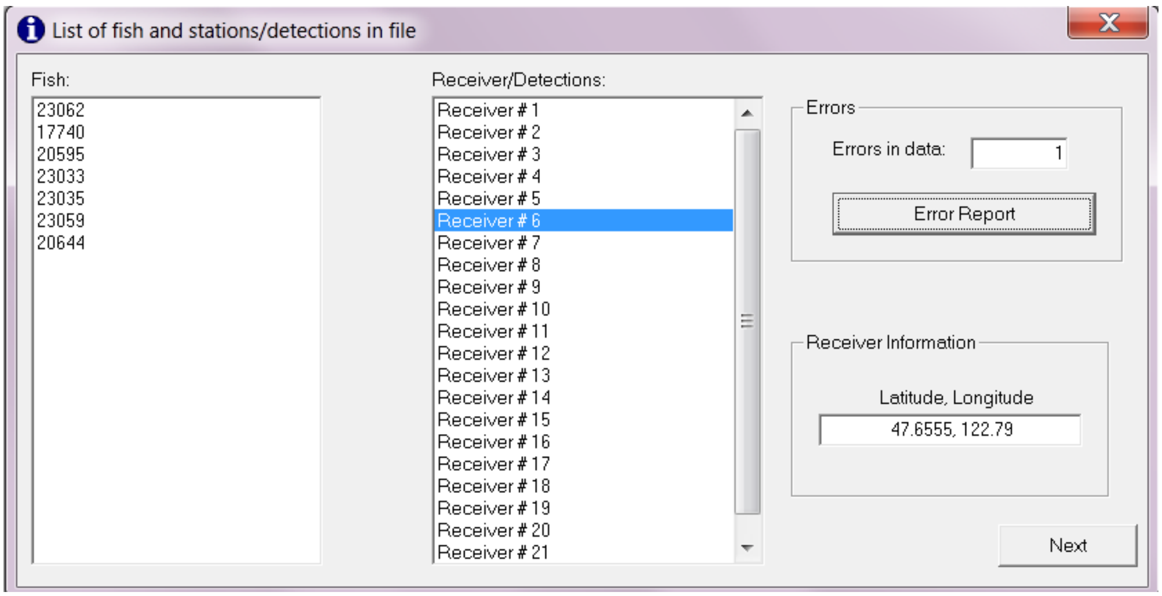
1) Export as is: The program simply writes the row with the error and does not change anything about it.
2) Discard rows: The program does not export the row with the error. This is the easiest option to use and is recommended for most situations.
3) Add dummy but valid data: This option can actually fix some problems but it can also introduce errors in your data. In the example here, a wrong latitude was placed in the spreadsheet. The program will seek another valid latitude for that receiver and substitute it in place of the wrong one.

Select an option and click **NEXT**. The program will begin processing the data in the file. For large files, this may take a minute or two. You may also get additional information about the error and how it was fixed.

# Auto-naming of receivers

If the converter program does not find a valid receiver name column or if you check the box "**Override receiver names**" on the first window, the program will attempt to auto-name the receivers depending on their coordinates. Each unique coordinate gets a receiver number. This is ideal if you are trying to quickly visualize a small set of mobile receiver detections, as the converter will create an AquaTracker import-ready file without having to come up with names for each coordinate!

To give each receiver a unique name, click on the receiver. The program will ask if you want to exclude it. Click on **NO**. The program will now give you the alternative to rename the receiver instead.



# 1.3 The AQN file format


***AquaTracker*** 2.4 features a new native format we call AQN (for AQuatracker Native format). Once you load a CSV file, you can use the **File→Save as AQN…** to save the file in this native format. Beware that some files will increase in size. Besides the stamps, AQN files store the following additional information:

1) Receiver marker type and color
2) Receiver groups
3) The color of fish tracks
4) Routes calculated by any of the land-avoidance algorithms. The waypoints for the routes are stored. The routes will only work with the map which was used to create the route.

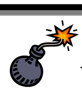
In addition, once a file is saved in the AQN format, <u>the program will remember the name and location of the file the next time it is started</u> and will ask you if you would like to load it again.

# 1.4 Loading a map

***AquaTracker*** can work with a geo-referenced map with known control points but remember that the analysis of the data can be done <u>without</u> a map.

To load a map, go to **Map→ Load From BMP**. ***AquaTracker*** will ask if you want to **accept the map**. If your intention is to use this map for land-avoidance and/or to enable all of ***AquaTracker*** features, click on YES to accept the map. If this map has NON-WHITE pixels as WATER, you may want to click on NO first to ignore the map, and then select a water pixel by following the procedure outline below.

The map will now automatically be loaded and read every time you start ***AquaTracker.***

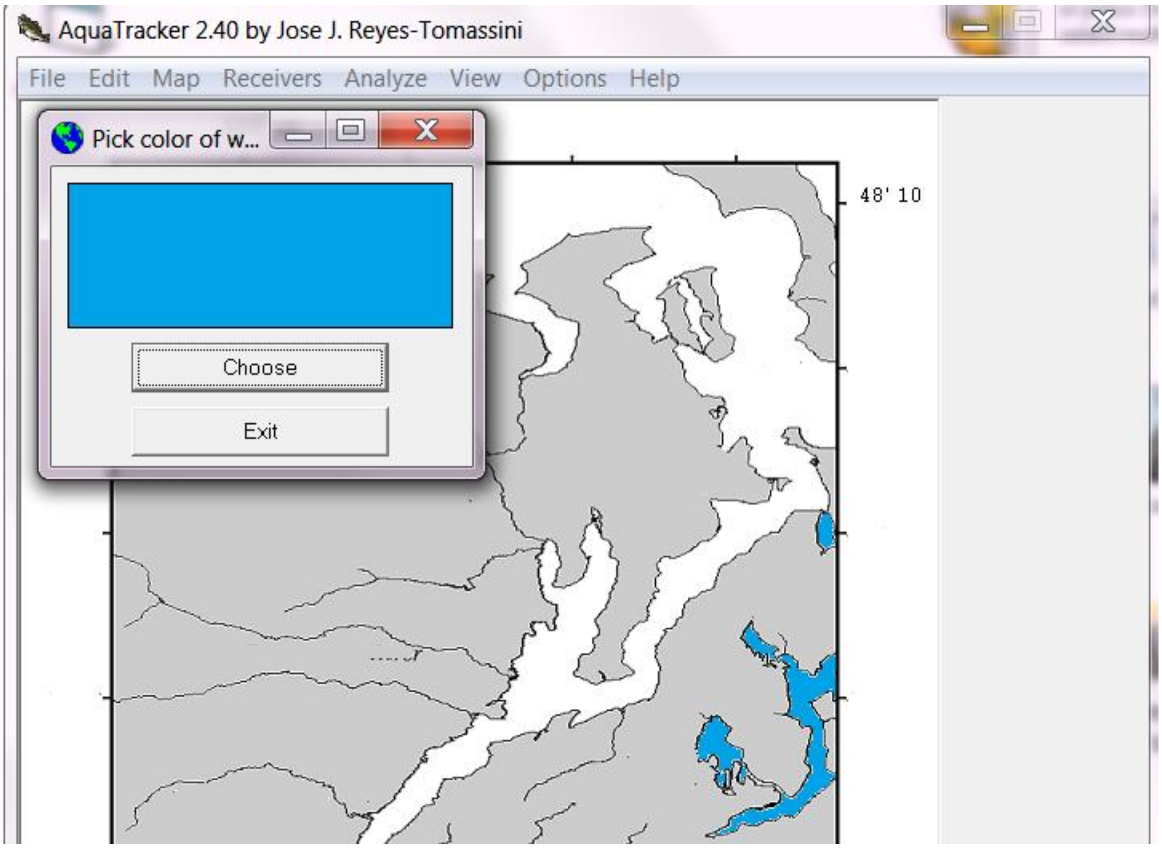


**WARNING**: Any BMP file can be used but the current version will not work if a map is bigger than 1024x1024 pixels. You can convert any map to this size. Refer to the FAQ document for more information on what files can be used as map files.

# 1.5 Selecting water pixels (for maps with water as non-white pixels)

***AquaTracker*** will "see" any white pixel as a water pixel unless you first indicate to it the correct color of the water in your map. You do not need to worry about this if you are not going to be using land-avoidance, so you may want to skip this section if that is the case. Also, if your map uses white as the water color, you do not need to perform this procedure at all.

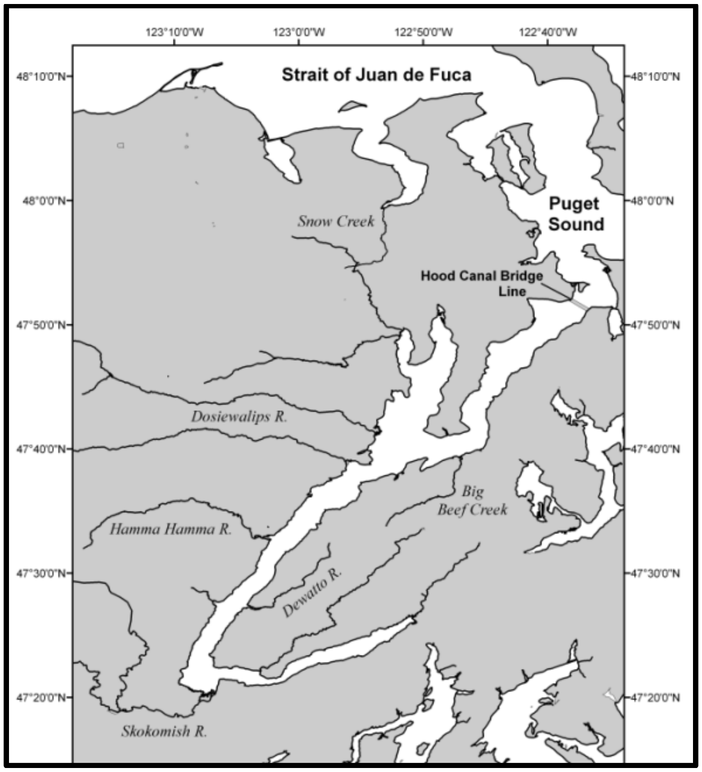
To select a water color, go to **Map→Pick color of water**. **AquaTracker** will show a window and a color picker. Click on a part of the map that has a water pixel. When you are satisfied that you have the right color, click on **Choose**, then you can continue with the rest of the procedures outlined in the next section.

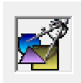



***NOTE:*** *If your map uses shades of color (i.e. more than one color to represent the water) you may want to "reduce" the colors in the image, turn it into a black and white image, or colorize it with a single color for water by using an image editor.*

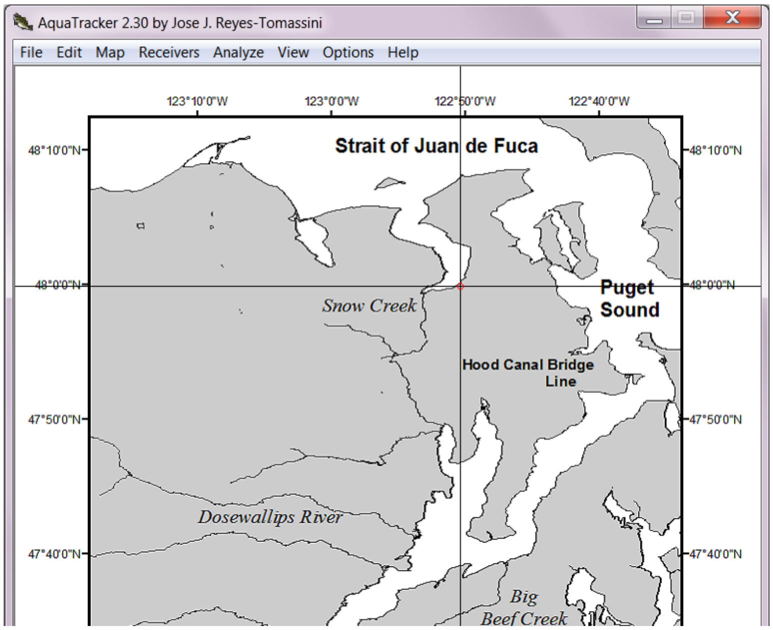
# 1.6 Creating a Geo-referenced Map

To create a geo-referenced map, you will need either a map with two defined control points or a map that has a Long/Lat coordinate scale as shown below:




Go to **View→Actions** to display the Actions window. Select the Set Control Point tool  from the actions window tool bar.


***AquaTracker*** will show a pair of cross hair with lines extending in opposite directions perpendicular to the cursor. These lines allow you to use the scale on the map.



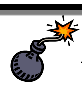

You can use the scale to know the approximate latitude and longitude coordinates for this point, as illustrated in the figure above.

**AquaTracker** will draw a red circle where this first “control point” is.

Enter the coordinates, in the format: DEGREES’MINUTES (e.g. 122’30).


For added accuracy, you can also enter the coordinates as decimal coordinates (e.g 122.50 degrees).

Repeat these steps with a second control point. **AquaTracker** will draw a blue circle for this second point and ask for its lat/long. After your second control point is set, your map is georeferenced!



**WARNING: Be sure to click on the Arrow icon (select tool) again. Otherwise, you might change the control points by inadvertently clicking on the map!**

# 1.7 Working with a blank canvas

If you do not have a map, you can work with a blank canvas. To do this, go to Map on the main menu, then select NEW BLANK CANVAS. The program will prompt you to enter the height of the canvas in pixels. The height of the previous map will be automatically entered for you as the default, but you can change it to whatever height you would like (no larger than 1024x1024). Next, the program will ask for the width of the canvas. Again, the default size will be the size of the map that was previously loaded in memory.

**Remember the maximum size of the canvas is 1024x1024**.

After you enter the dimensions of the canvas, the program will ask you if you want to use your data to automatically select the scale used. This is done to ensure that the data is displayed best and that all the canvas is used to display the data.

Finally, **AquaTracker** will ask if you want to re-plot the receivers and other spatial information (such as Zones, Groups, etc.). If you have data already loaded into memory, you should answer YES to this question. Otherwise, the program could crash or behave erratically while performing any graphing function.

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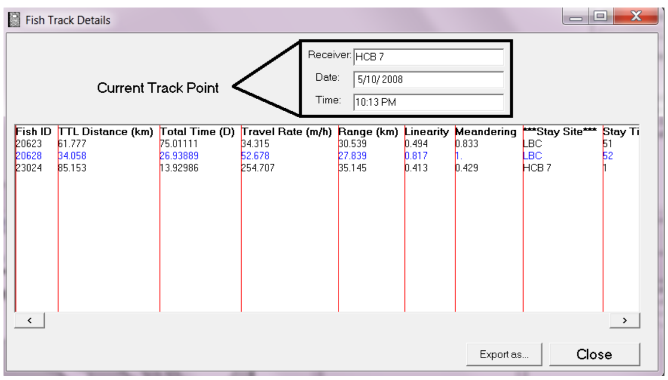
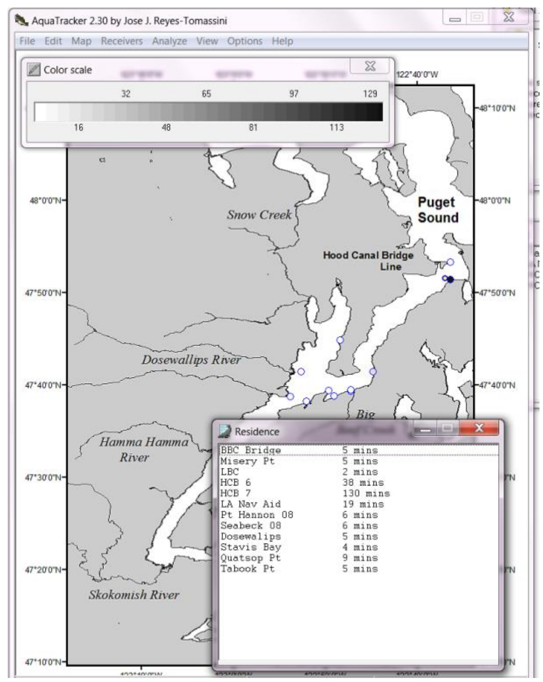
# Chapter 2: Data Exploration tools

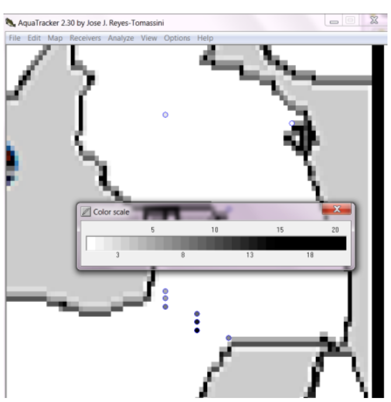
**AquaTracker** allows you to explore the receiver data in multiple ways. Internally, the data is stored in two different *data containers*: a *receiver container* and a *fish container*. To understand data analysis in **AquaTracker**, it is useful to keep in mind this data model. The information stored in the *fish container* becomes the track, and the *receiver container* has the information which when processed by the program becomes the residence time, excursion time, detection density, etc. **In this chapter you will learn how to use AquaTracker to explore both the receiver detections and the fish track data.**




Track information displayed when animating tracks



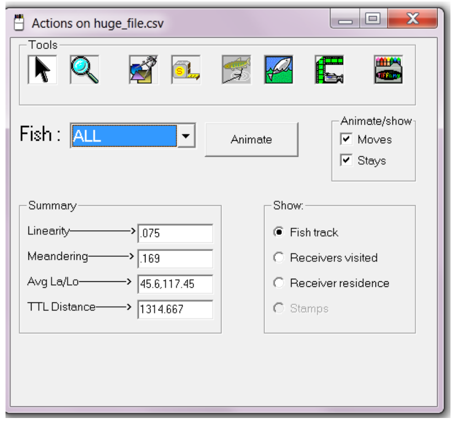

Time spent at each receiver by a fish can be shown as a function of a grey-scale heat-map.



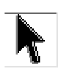

Zooming in on the line at the Hood Canal bridge in Puget Sound reveals the number of fish detected at different points along the bridge using the receiver density by fish tool.

## 2.1 Actions window

Once a detection file has been loaded, **AquaTracker** will display all the tracks in the file simultaneously. It will also show a small, “floating” window, called the **Actions** window.



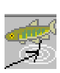

***NOTE:*** *The Actions window can be shown before data is loaded (i.e. if you need to set the control points) by going to* ***View→Actions Window****.*

 Together with the context menu for the receiver, the selection tool is used to obtain information about receivers and to select multiple receivers into a receiver group or draw a “geotag” zone.

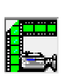
 The zoom tool allows you to focus on a particular area of the map to better visualize receivers and tracks.

 Map calibration tool is used in AquaTracker only to geo-reference a map or canvas

 The tape measure tool is used to find the distance between two points in a map or canvas

 Fish track reference tool is used to draw a reference track for analysis or to analyze a reference track already selected

 Fish corridor tool is used to draw fish corridors in the map. In combination with land-avoidance, it allows you to force the path of the fish so that it “stays in the water”

 Animation/canvas capture tool. For computers with available codecs (most comptuers with stock versions of Windows), creates an AVI file that can be played as part of a scientific presentation. An example demo AVI is included in the installaton package

 The color selector tool is used to select a track color for the selected fish track

# Track options

□**Moves**: If moves are checked in the checkboxes, then the track will consits of arrows pointing to the direction the fish moved between detections.

□**Stays**: If the stays checkbox is selected, the receivers where the detections occurred are shown (as solid markers).

## Show options

◯ Fish tracks: Shows both moves and stays in the canvas

◯ Receivers visited: Shows stays only

◯ Receiver residence: Shows the time spent at each receiver

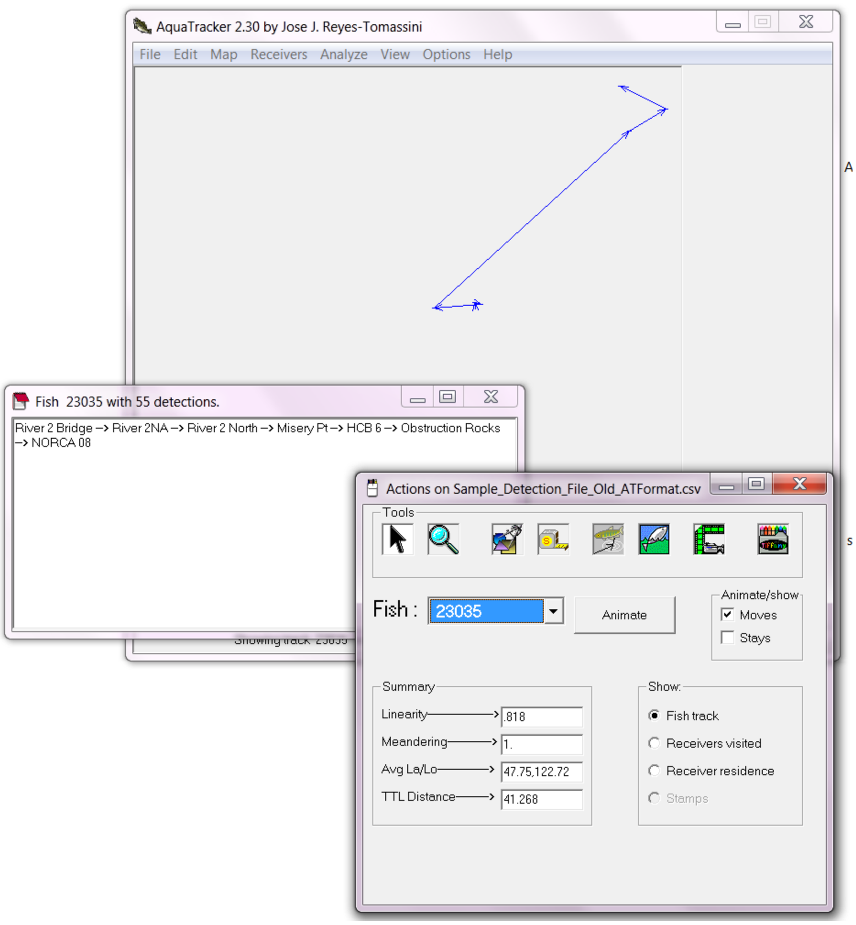
◯ Stamps: Shows a dialog window with a verbose description of each detection

# Displaying and animating a fish track

**AquaTracker** will show a single **fish track** once you select a fish code from the drop down menu in the **Actions window**. Lines with arrows pointing towards the direction the fish moved will be displayed in the main canvas window. The SHOW radial button section in the Actions window affects what is shown when a user selects a fish from the fish drop down list. You can select to show either MOVES or STAYS or both by checking the checkboxes on the **Animate/show** section of the **Actions window**. A **Track String window** will also come up, and it will include a verbose description of the track. You can highlight a receiver or track segment by selecting the text description in the **Track String window**.

In the fish drop down list, select ALL to show all the fish and all the receivers in the file.

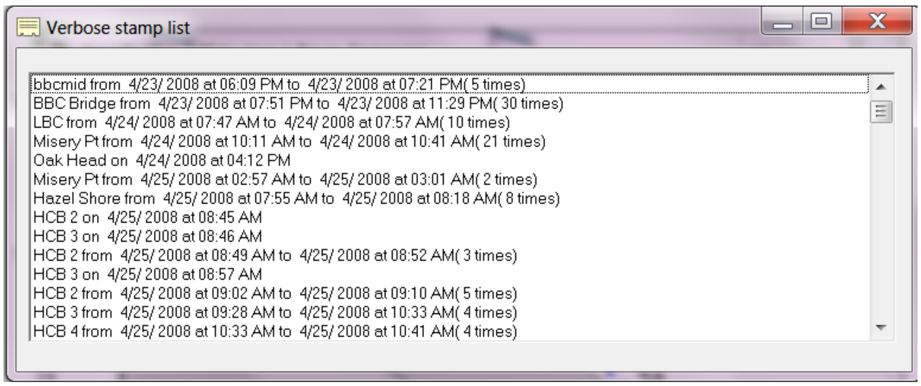
Click **Animate** to start an animation sequence of the fish track.



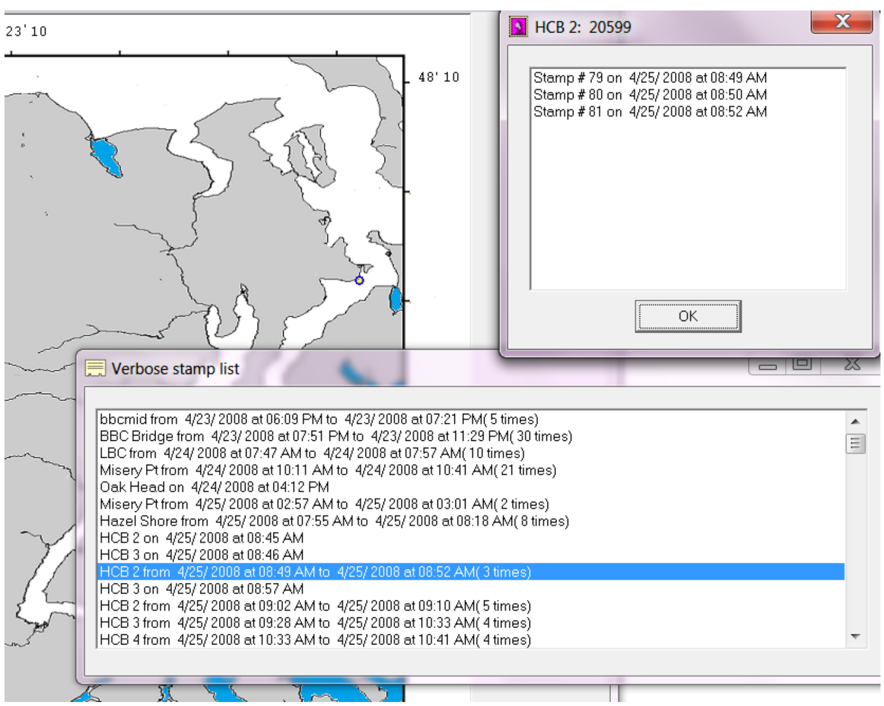

**Hint**: When a track is displayed, you can right-click any of the receivers in the track to reveal the **Receiver Context Menu**. Choose **Show stamps→Track-specific pings** to see the "pings" or stamps that the fish in the displayed track generated on the selected receiver.

# Verbose stamp description: Interactive stamp explorer

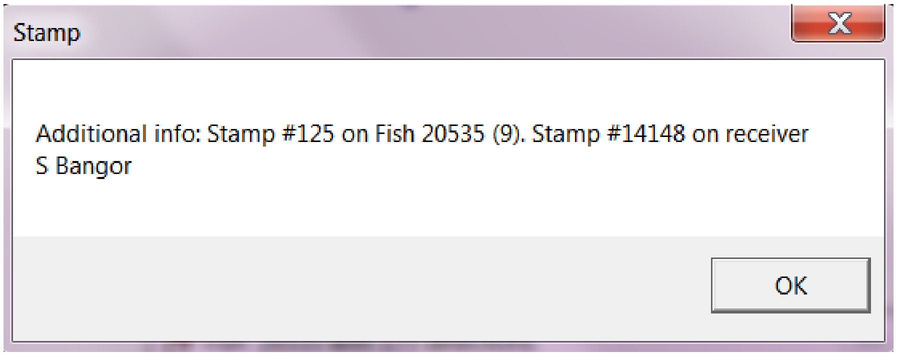
Selecting to show the verbose stamp description allows you to see the actual stamps in a track. AquaTracker will still draw the track and show the track string, but you will now be able to see the stamps that generated the track. At the end of each stamp description, the program also shows you how many times the fish was continously detected within the period covered by the stamp.




The Verbose Stamp List window is interactive. If you double click on any of the stamps, you will get a list of the fish stamps. The program will also highlight in the canvas the receiver which generated the stamp.




Clicking on any of the stamps in the stamp dialog window shows above (e.g. "Stamp #xxxx on dd/mm/yy…") will open up a third window which contains a cross reference of the stamp in the receiver that generated the stamp in the fish.




Note that collecting this cross-referenced information may take time so be patient when you click on the stamp dialog window if you have too many continous detections.

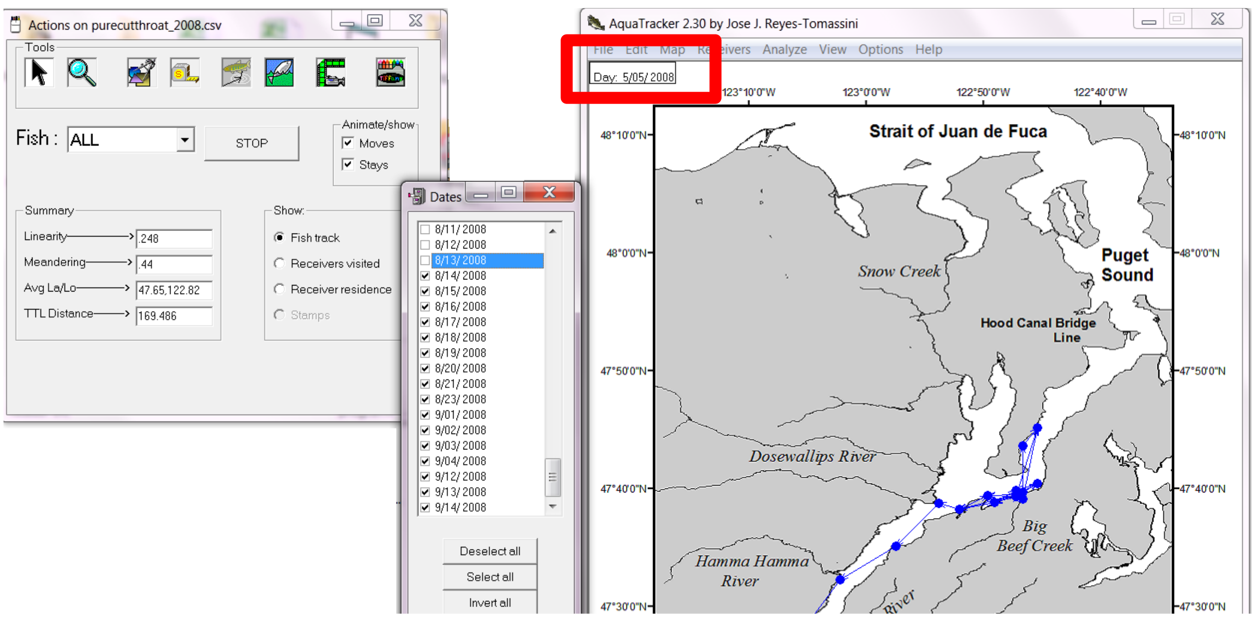
The above example shows that the stamp on which the user clicked is the 125$^{th}$ stamp on the fish list of detections that created the track (e.g. the fish detection container). The fish ID is "20535" and it's the 9$^{th}$ fish in the pulldown menu list on the Actions window. The stamp was generated by Receiver "S Bangor". It is the stamp number 14,148 out of all the stamps in the receiver.

If the stamp was generated by a receiver in a group, the name of the receiver before linking it to the group is shown in this window, althought the stamp number still corresponds to the group's aggregated stamp count.

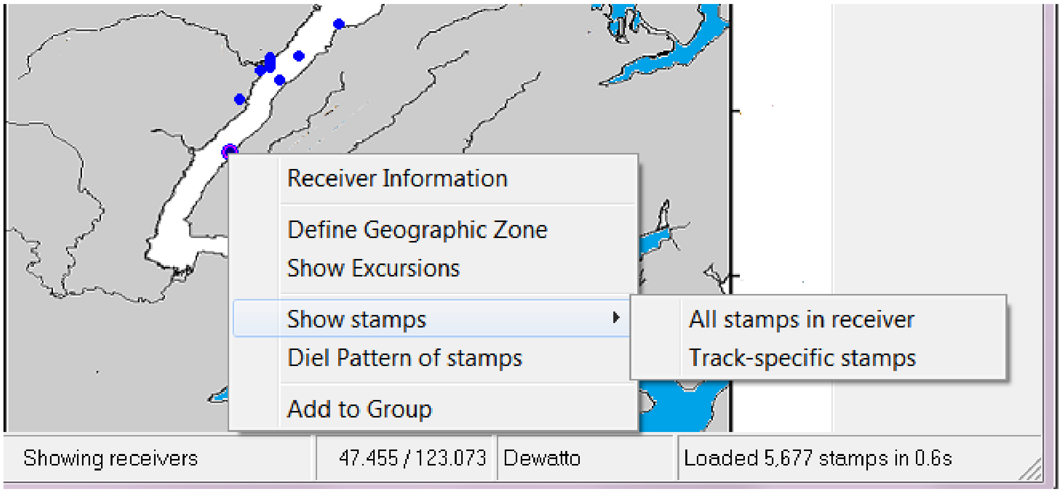
# The "Play All Tracks" option

If you have selected ALL on the fish menu and you click on **Animate**, then the animation will show the daily fish movement until the last fish move is drawn on the canvas. Note that this can take some time to animate depending on how big the dataset is. When playing all tracks, **AquaTracker** will automaticall load the **Day List** window. You can make some days invisible by unselecting them from the list. Click on **Animate** again to see the effect of "skipping" those days or finishing/starting the animation at a different day!

The plotted day is shown on the upper left of the canvas as can be seen in the screenshot below on the red box. For options related to how **AquaTracker** animates the track see 7.1 Animation options.



# 2.2 Receiver Context Menu




Right-clicking on any of the receivers when the Selection Tool is selected on **the Actions window** displays the **Receiver Context-Menu.**

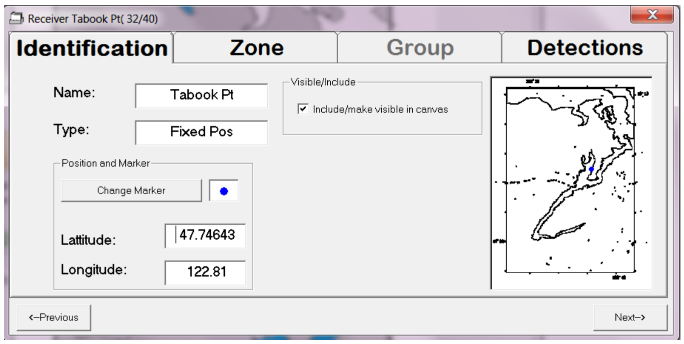
The **Receiver context-menu** allows you to perform several different actions on the selected receivers, including adding the receiver to a receiver group, showing track specific-pings, etc.

## 2.3.1 Receiver Information Window

The **Receiver Information window** allows you to browse all the information stored in memory about the receiver, the marker used to shown the receiver, its location, the fish detected at the receiver, the zones and tags it is associated with, and the receiver grouping information.

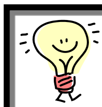
The Receiver Information window displays this information in a multi-tab format.

## Identification Tab




This tab contains information about the identity and location of the receiver. A scaled-down map of the one in the canvas is displayed (if a map has been loaded) where the location of the receiver is shown.

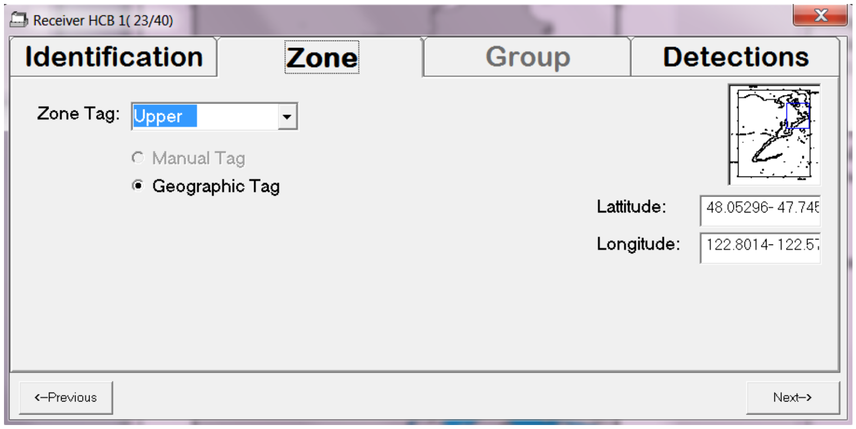

If a receiver does not belong to a group or is not the group's representative receiver, you can use the checkbox **Visible/Include** to force the receiver out of the analysis and make the receiver dissappear from the map.



**Hint**: When a receiver group is created, a *representative receiver* is "deployed" and added to the database. The representative receiver is deployed at the average coordinates of the group. This representative receiver can be excluded/included from the analysis but the receivers that form the group will now be set to "Excluded" and you won't be able to set the **Visible/Include** property. For this groupped receivers, the checkbox will be disabled (greyed out).

To find out how to change the marker color, marker type, and how to setup a distance-based heat-map see seciton 4.3 Detection Scatter Plot with distance-based heat map.

## Tag/Zone Tab

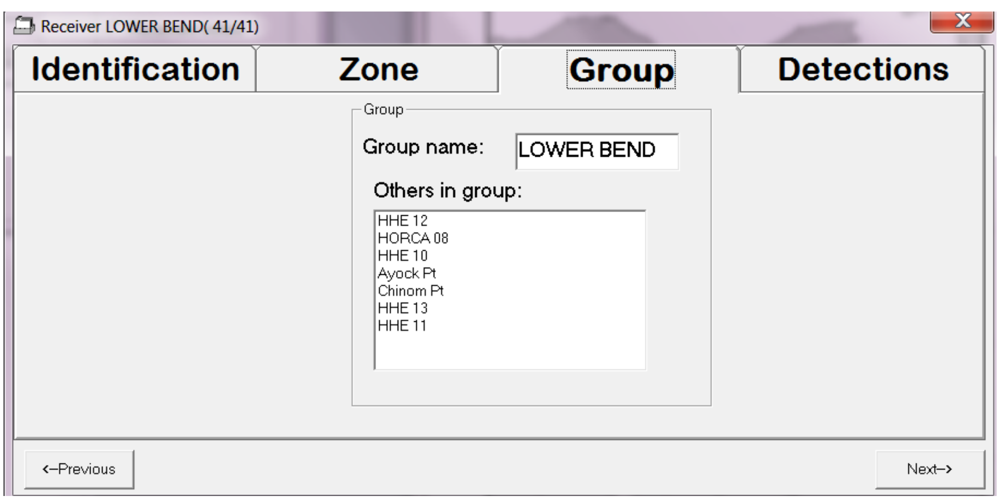



This tab displays information about the tag zone that the receiver belongs. This is the the place in ***AquaTracker*** to define a tag zone manually To do this, select ADD NEW TAG from the Zone Tag pull-down list. The new tag will appear on this list and can be used in other receivers.

A zone tag can be defined manually or by first defining a geographic boundary. Receivers with coordinates that fall within the bounds of this geographic zone will be automatically tagged with this **Geographic Tag**. For more information on this feauture see section 3.6 Tag Analysis.

When using geographic tags, the latitude and longitude of the geographic tag bounding area will also be shown on this tab. The scaled-down map in the window shows the tag zone boundaries.

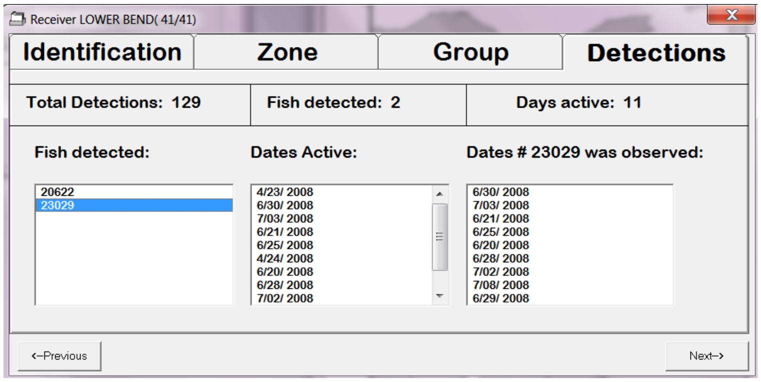
## Group Tab





When a receiver belongs to a *receiver group*, the group tab shows the name of the group and the name of the receivers in that group. For more information on groups see 3.2 Grouping Receivers

## Detections Tab



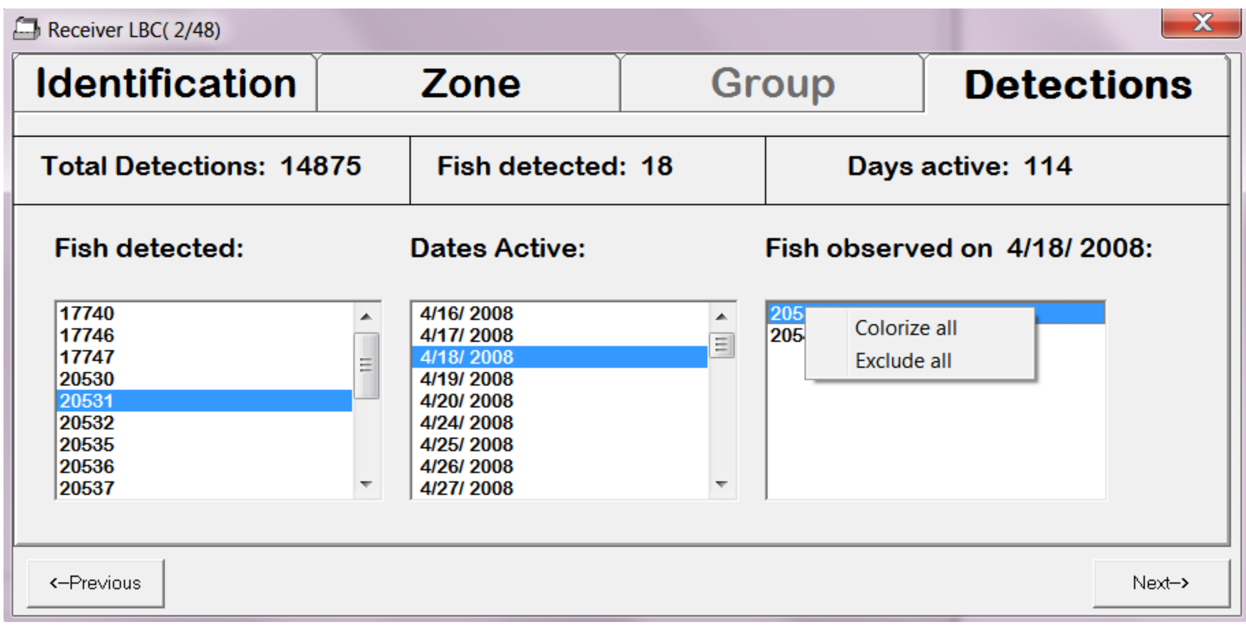

The Detection tab displays information about the receiver detections (**stamps**). The fish detected are displayed in the list to the left. The dates when the receiver had detection activity is displayed in the middle list. The total detections, total fish detected at the receiver, and the total number of days when the receiver had any detections is also shown. When receivers are grouped, the combined detections of all members of the receiver group are shown.

**Hint**: To see what fish are detected on a specific date, click the date on the list. To see when a specific fish on the list was detected, click on the fish code on the list. Doing any of these two actions will cause the program to display a small list box on the far right of the window with the fish codes or dates, as shown on the figure above.


You can click on each fish id on the list boxes in this window and it will display the fish track and information on the main window. You can also right-click on the window while its showing the fish list to show the fish detection context menu. This menu has two options:

**Exclude all**: Exclude the tracks on the list. You can use this feature to exclude all the tracks going thru a specific receiver. You can also use this feature together with the fish track exclusion feature Invert button (see ) to only show tracks from this receiver. In addition, you can use this feature to exclude fish tracks going thru a specific receiver on a specific date. Similarly, using the Invert button in the fish track exclusion window, you can show only tracks going over the receiver on a specific date.

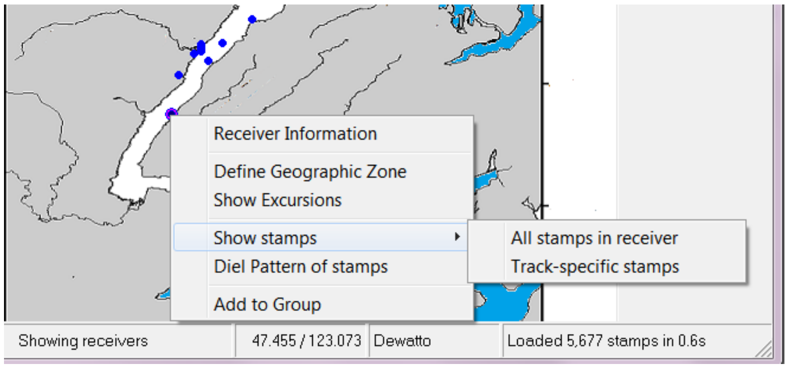
**Colorize all**: Colorizes the tracks on the list. You can use this feature to give tracks going thru a specific receiver or a specific region (where one or more receivers are located) a different color on the map.



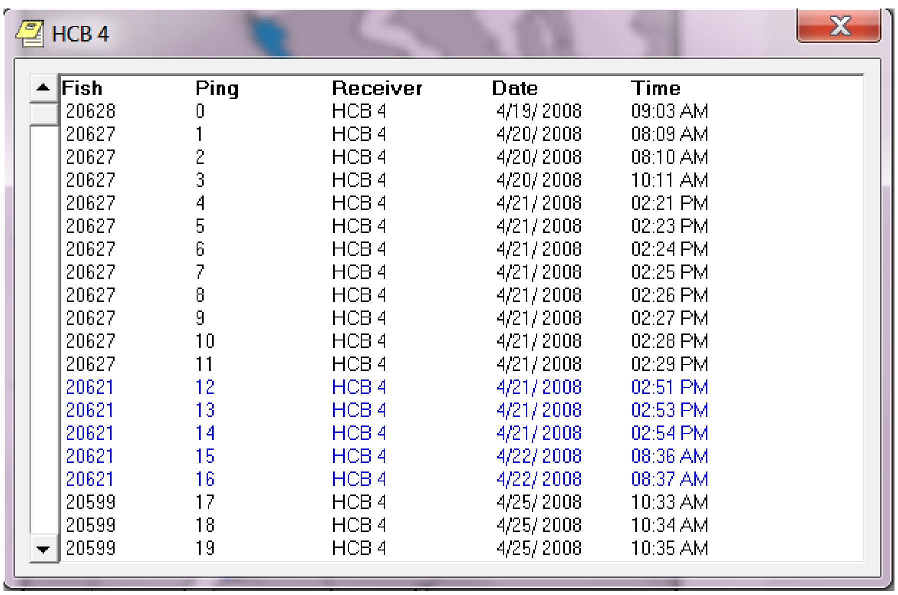
## 2.3.2 Show Excursion

Shows the excursions of fish from the selected receiver or groups of selected receivers. To learn more about this feature see section 3.5 Excursion Analysis.

## 2.3.3 Show Stamps: All stamps in receiver/Track-specific stamps




This option allows you to see the detections or ***stamps*** in a receiver. You can select to see **All stamps in receiver** or to see only the **Track-specific stamps** belonging to the fish track currently selected in the **Actions** window. Notice fish id number alternate colors on the list so you can easily find specific fish among the list.




| Fish | Ping | Receiver | Date | Time |
|---|---|---|---|---|
| 20628 | 0 | HCB 4 | 4/19/ 2008 | 09:03 AM |
| 20627 | 1 | HCB 4 | 4/20/ 2008 | 08:09 AM |
| 20627 | 2 | HCB 4 | 4/20/ 2008 | 08:10 AM |
| 20627 | 3 | HCB 4 | 4/20/ 2008 | 10:11 AM |
| 20627 | 4 | HCB 4 | 4/21/ 2008 | 02:21 PM |
| 20627 | 5 | HCB 4 | 4/21/ 2008 | 02:23 PM |
| 20627 | 6 | HCB 4 | 4/21/ 2008 | 02:24 PM |
| 20627 | 7 | HCB 4 | 4/21/ 2008 | 02:25 PM |
| 20627 | 8 | HCB 4 | 4/21/ 2008 | 02:26 PM |
| 20627 | 9 | HCB 4 | 4/21/ 2008 | 02:27 PM |
| 20627 | 10 | HCB 4 | 4/21/ 2008 | 02:28 PM |
| 20627 | 11 | HCB 4 | 4/21/ 2008 | 02:29 PM |
| 20621 | 12 | HCB 4 | 4/21/ 2008 | 02:51 PM |
| 20621 | 13 | HCB 4 | 4/21/ 2008 | 02:53 PM |
| 20621 | 14 | HCB 4 | 4/21/ 2008 | 02:54 PM |
| 20621 | 15 | HCB 4 | 4/22/ 2008 | 08:36 AM |
| 20621 | 16 | HCB 4 | 4/22/ 2008 | 08:37 AM |
| 20599 | 17 | HCB 4 | 4/25/ 2008 | 10:33 AM |
| 20599 | 18 | HCB 4 | 4/25/ 2008 | 10:34 AM |
| 20599 | 19 | HCB 4 | 4/25/ 2008 | 10:35 AM |

## 2.3.4 Diel Pattern of Pings

This graphing function will show a histogram of the detections in relation to time of day for the specific receiver you have selected or the receiver group you have selected. When using this feature from within the context menu, the data shown will be **track-specific**. To learn more about this program feature see section 5.1 Diel Pattern of Detections

## 2.7 Add to group

Manually adds a receiver(s) to create a group of receivers. Receiver groups are treated as a single receiver for most analyses done within the program. To learn more about what are receiver groups and when you might need to group receivers, see section 3.2 Grouping Receivers.

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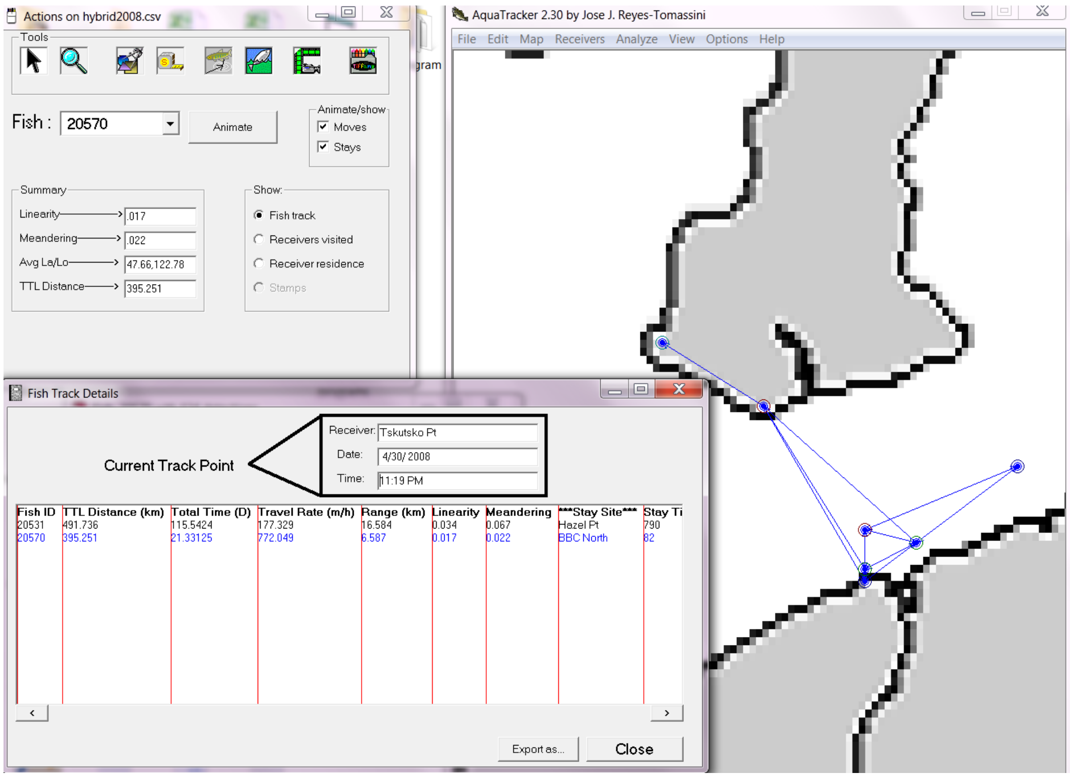
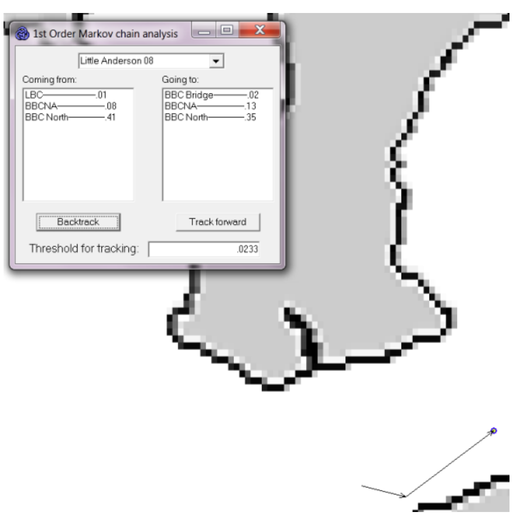
# Chapter 3: Analysis Tools

**AquaTracker** offers a variety of analysis tools. Tracks, receivers, and group of receivers, can be analyzed individually. Alternatively, all the receivers or fish tracks can be analyzed at once by using any of the export functions, which create CSV files that can be read in any spreadsheet. **In this chapter, you will learn about the different analyses that can be performed with the program, and how to export the analyzed data to CSV files.**




Animations in AquaTracker show the direction of movement of the fish and the stays at different receivers. Track details are shown on a separate Fish Track Details window



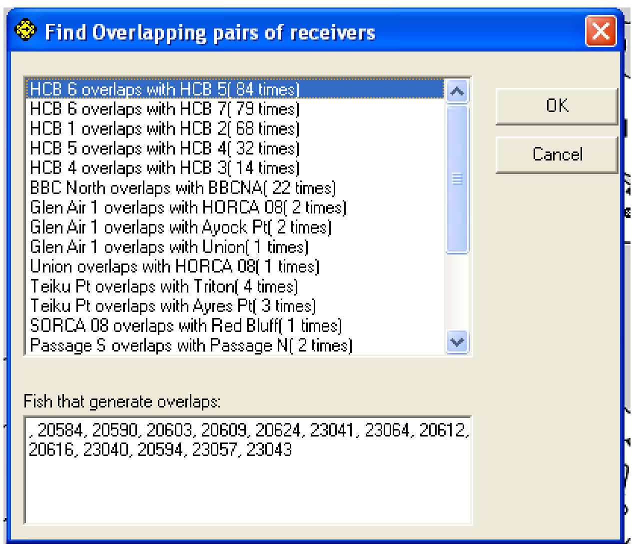

Want to know what routes the fish usually travelled to and from specific receivers? A simple Markov chain tool allows you to visualize the "typical" routes the fish took to go from one receiver to another.

## 3.1 Finding Overlapping Receivers

Occasionally a receiver array will have one or more receivers that have overlapping detection radii. This might be done intentionally (i.e. lines, gates, etc.), but can also occur inadvertently. Regardless, both receivers might detect the same fish at almost identical times, even when the receivers are hundreds of meters apart. To detect such events, **AquaTracker** can perform an **overlap analysis**. To do this, go **to Analyze→Receiver Overlap Analysis**.

> **NOTE**: *<u>It is highly recommended that you run an overlap analysis before performing any other calculations</u>. Some of the calculated parameters (e.g. Ranging Index) rely on the assumption that receivers do not overlap. By using overlap analysis together with the auto-grouping option (see below), you will not be violating this assumption.*

When you instruct **AquaTracker** to find overlapping receivers, it will first ask you the threshold for the overlap. The default (based on both the known radius of detection and the minimum travel speed of fish) is 1 minute. After you enter the threshold, **AquaTracker** will display the following window:




In the scrollable list box, the overlaps are shown. The number of times that an overlap was generated is shown in parenthesis. Select any of the overlaps to reveal the fish that generated the overlap, listed by their *fish id*. Note that when you select the overlapping pairs, **AquaTracker** will also show the overlaps on the main canvas window (in red). This allows you to visualize the relative location of these overlaps.

**If you do not believe the overlap is <u>real or is an error due to clock drift</u>, you can press the delete key on the keyboard (or double click on the overlap) to remove the overlap pair from the list.**

Hit OK to accept the overlaps listed. **AquaTracker** will now ask you if you wish to use the overlaps as the basis to automatically generate receiver groups. Once you click OK, a new window will be displayed allowing you to make changes to the groups such as changing the name of the group, deleting receivers in the groups, etc. (see section 3.2 Grouping Receivers).

The program does not allow you to perform nested overlap analysis on the data set. Thus, once a data set has been analyzed for overlaps, the overlap function is disabled in the menu. This is because nested overlap analysis make no sense and could cause the program to crash.

## 3.2 Grouping Receivers

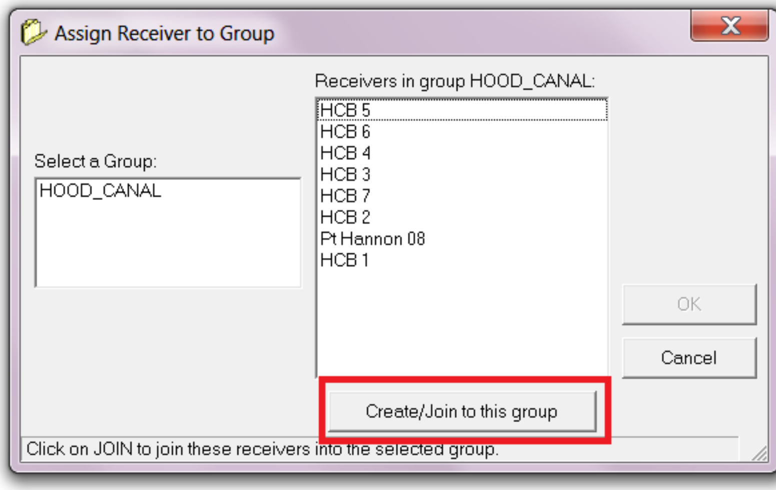
In some circumstances, you might want to group receivers together by manually assigning them to a group. Receiver grouping can also be used if the general location of a fish is more important than the specific receivers in which it was detected, and the geometry of the array is such that different group of receivers share a common location. For these special cases, ***AquaTracker*** allows you to *group* receivers directly (without using **Overlap Analysis**).

> **NOTE**: ***AquaTracker*** *will treat grouped receivers as a single receiver, so that X and Y coordinates, excursions, travel distances, etc. are all affected by grouping.*

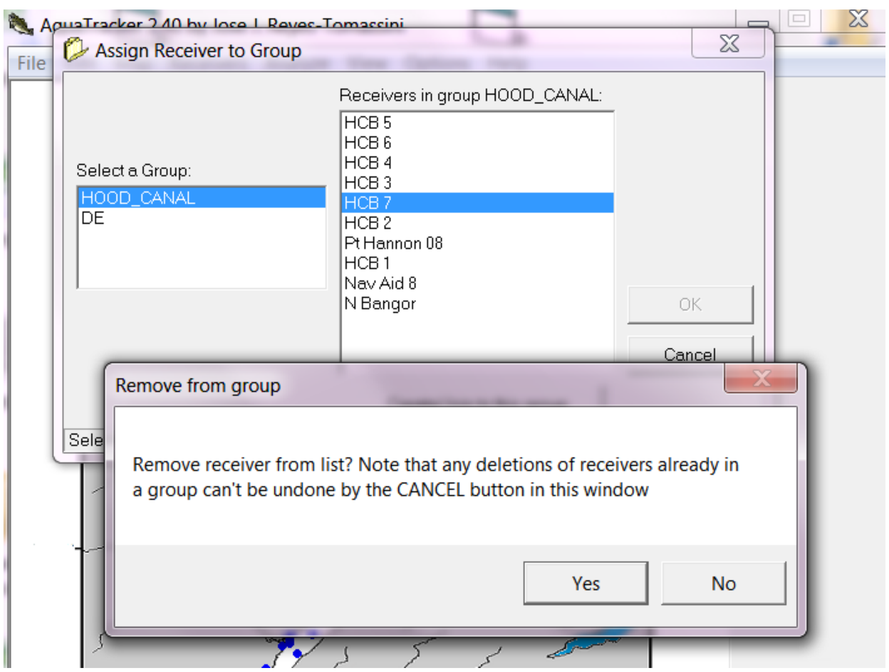
To group receivers, you can multi-select (**SHIFT + LEFT BUTON**) the receivers and then right-click and choose **Add to Group** from the **Receiver Context Menu** (see for more information). Alternatively, you can simply add receivers one by one, selecting them by right-clicking on each of the receivers, then choosing **Add to Group**.

After **Add to Group** is selected the program will prompt you to name the receiver group. Press **ENTER** if you want to add the receivers to an existing group, otherwise enter the receiver group name you would like to use. Keep in mind that group names are not cap sensitive and can contain any valid character except the "," (comma).


After entering a name or leaving the name field blank, the **Group Receivers** window is displayed. This window has a list of the receiver groups in the database (including the new one that you have created). On the right hand-side, the window will also show you a list of the receivers you selected. If there is more than one group in the database, you can click on the group and the receivers you selected will be added to this group. You will need to click on **CREATE/JOIN TO THIS GROUP** if you would like the current receiver(s) to become part of the group. Once you do this, you will also need to click **OK** to make the change permanent.

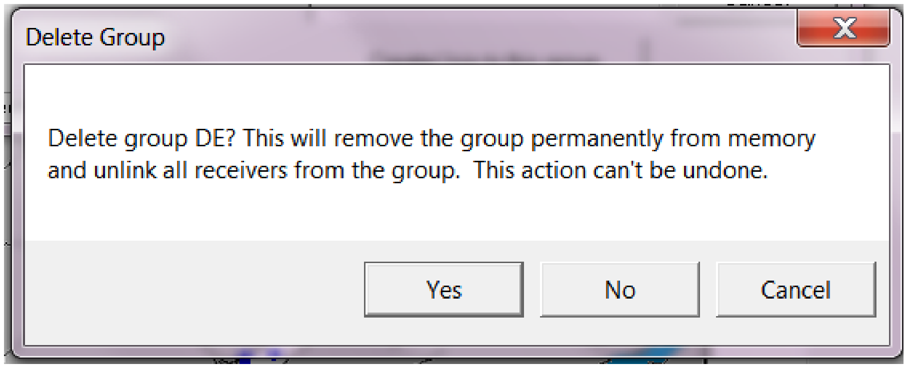



To delete a receiver from a group, double-click the receiver name on the list to the right. A window asking you to confirm will be displayed. This window will also warn you that you can only delete a receiver from a group at the time the group is created. Otherwise, you need to delete the group and create a new group.




**Hint**: You can automatically create groups by doing an Overlap Analysis (see above), then answering Yes to "Automatically Create Groups".

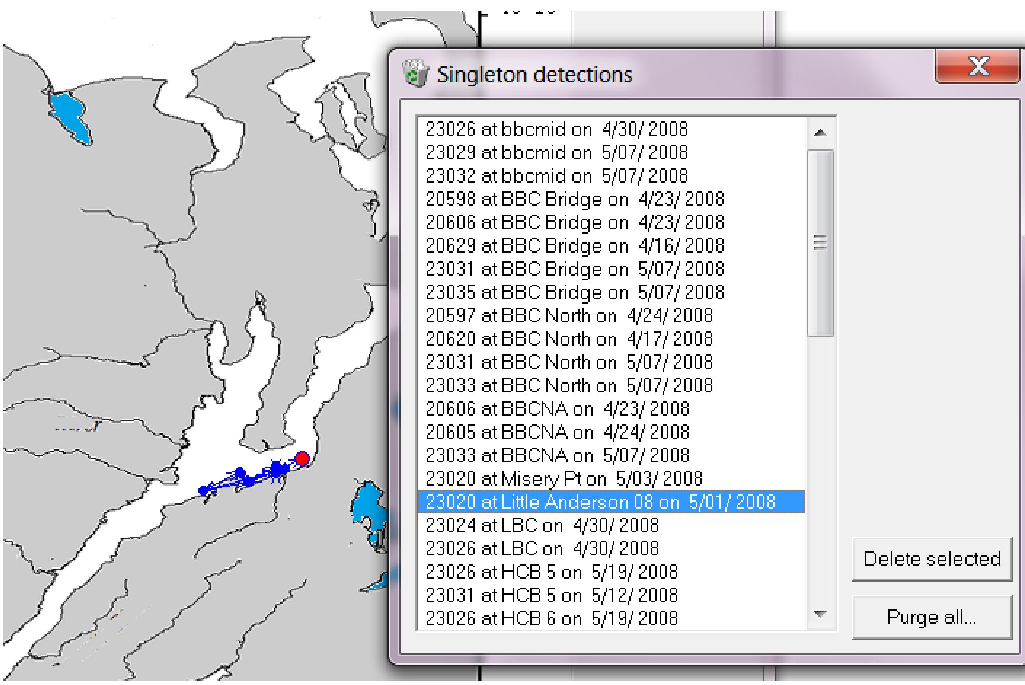
To delete a group, double-click on the group name in the list to the left. A warning window asking you to confirm the change will be displayed. This window will also warn you that deleting a group is not a change that can be undone.




## 3.3 Identifying singleton detections

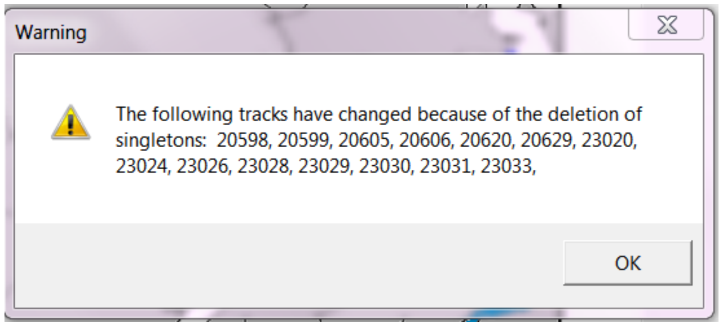
Singleton detections are those in which only a single ping was generated by a fish in a 24hr period. These types of detections are assumed to be usually created by noise and should be identified before proceeding with further analysis of the data.

AquaTracker will analyze the detections and identify the singletons by date, receiver and fish code. To find the singletons go to **Analyze→Show singletons**. Once the analysis is completed, the program will show a list of singleton detections. Click on the detection to the fish track. The receiver where the singleton occurred will be highlighted as shown below.



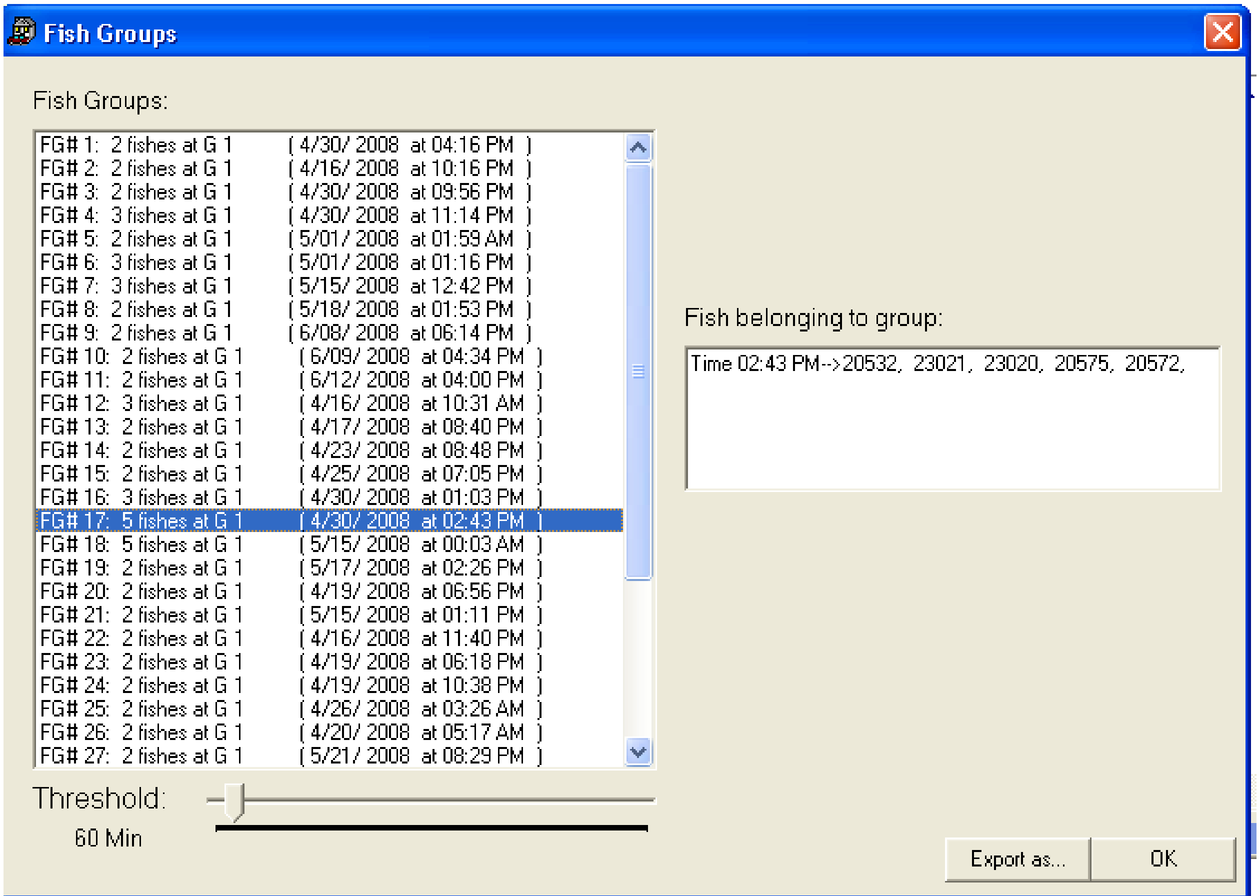

To remove only the singleton you have highlighted, click on **DELETE SELECTED**. To remove all the singletons in the list, click **PURGE ALL**.

After you delete singletons from the database, AquaTracker will re-examine the tracks and let you know if any fish track changed as a result of deleting the singleton(s). The warning window will look something like the one shown below:




## 3.4 Identifying fish groups

To show the fish arriving together (co-detected) at any of the receivers or receivers groups in the experiment, go to **Analyze→Identify Fish Groups**. <u>It is suggested that an overlap analysis be performed before the identification of fish groups.</u> A threshold must be defined for this analysis. This threshold is a value that defines the maximum time that can elapse between co-detections. If fish #1 arrives at receiver A at 10:00am and fish #2 arrives at receiver A at 10:05am on the same day, then they are considered grouped if the threshold for co-detection is 5 minutes or more. If the threshold was set at 3 minutes, then Fish #1 and Fish #2 would not be grouped at receiver A. After the threshold is entered, the program displays the following window:

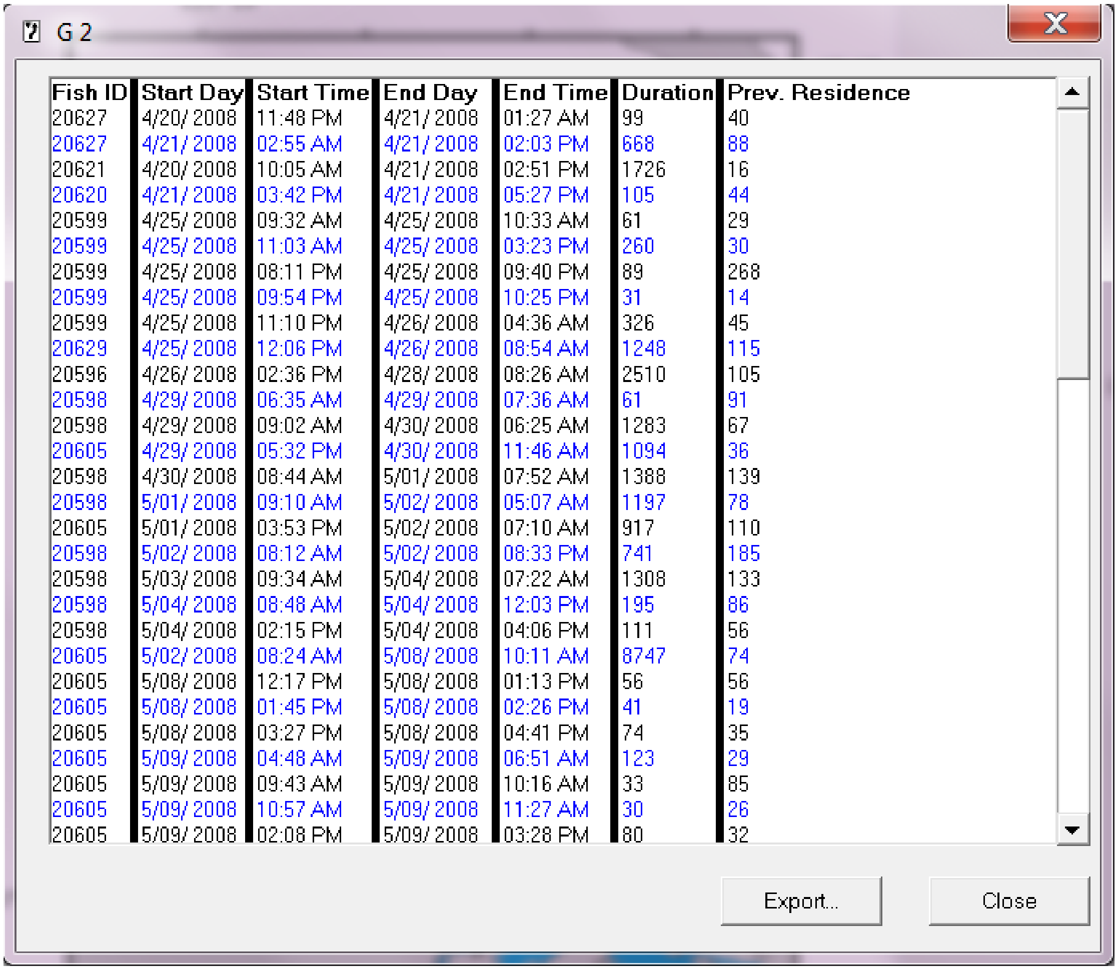



Where FG is the Fish Group number (an ID for the fish group), and the date stamp is the date and time when the last fish was observed within the threshold. Use the slider to change the threshold for co-detection. Select a fish group to reveal which fish are co-detected. To export the information in the window to a CSV file, click on the **Export as…** button.

A sample export file is shown below. The header shows the threshold used in the analysis (60 minutes). The first column, Column A, is the fish group number. Column B is the receiver name or the name of the receiver group (G1 is the group name in this example). Column C shows the number of fish in the fish group. Columns D and E show the time and date of the last detection in the fish group, respectively. The next columns (F and G) show the fish tag codes of the fish in the groups. A column is added for any additional fish in the fish group.

| | A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Aquatracker (c) by Jose J. Reyes | | | | | | | | | |
| 2 | | | | | | | | | | |
| 3 | Fish Group Analysis | | | | | | | | | |
| 4 | Threshold: 60 | | | | | | | | | |
| 5 | | | | | | | | | | |
| 6 | FG | Receiver(s) | Number of fish | Detection time (last) | Detection date (last) | Fish List | | | | |
| 7 | 1 | G 1 | 2 | 4:16 PM | 4/30/ 2008 | 20535 | 23022 | | | |
| 8 | 2 | G 1 | 2 | 10:16 PM | 4/16/ 2008 | 20571 | 20574 | | | |
| 9 | 3 | G 1 | 2 | 9:56 PM | 4/30/ 2008 | 20535 | 23022 | | | |
| 10 | 4 | G 1 | 3 | 11:14 PM | 4/30/ 2008 | 20572 | 20576 | 23020 | | |
| 11 | 5 | G 1 | 2 | 1:59 AM | 5/01/ 2008 | 20573 | 20576 | | | |
| 12 | 6 | G 1 | 3 | 1:16 PM | 5/01/ 2008 | 20532 | 23020 | 20601 | | |
| 13 | 7 | G 1 | 3 | 12:42 PM | 5/15/ 2008 | 20532 | 20572 | 28691 | | |
| 14 | 8 | G 1 | 2 | 1:53 PM | 5/18/ 2008 | 20532 | 20536 | | | |
| 15 | 9 | G 1 | 2 | 6:14 PM | 6/08/ 2008 | 20574 | 20537 | | | |
| 16 | 10 | G 1 | 2 | 4:34 PM | 6/09/ 2008 | 20537 | 20574 | | | |
| 17 | 11 | G 1 | 2 | 4:00 PM | 6/12/ 2008 | 20537 | 20574 | | | |
| 18 | 12 | G 1 | 3 | 10:31 AM | 4/16/ 2008 | 20538 | 20574 | 20536 | | |
| 19 | 13 | G 1 | 2 | 8:40 PM | 4/17/ 2008 | 20571 | 20536 | | | |
| 20 | 14 | G 1 | 2 | 8:48 PM | 4/23/ 2008 | 20575 | 20537 | | | |
| 21 | 15 | G 1 | 2 | 7:05 PM | 4/25/ 2008 | 20537 | 20575 | | | |
| 22 | 16 | G 1 | 3 | 1:03 PM | 4/30/ 2008 | 23022 | 20535 | 20601 | | |
| 23 | 17 | G 1 | 5 | 2:43 PM | 4/30/ 2008 | 20532 | 23021 | 23020 | 20575 | 20572 |
| 24 | 18 | G 1 | 5 | 12:03 AM | 5/15/ 2008 | 20532 | 20576 | 20571 | 20572 | 28691 |

## 3.5 Excursion Analysis




| Fish ID | Start Day | Start Time | End Day | End Time | Duration | Prev. Residence |
|---|---|---|---|---|---|---|
| 20627 | 4/20/2008 | 11:48 PM | 4/21/2008 | 01:27 AM | 99 | 40 |
| 20627 | 4/21/2008 | 02:55 AM | 4/21/2008 | 02:03 PM | 668 | 88 |
| 20621 | 4/20/2008 | 10:05 AM | 4/21/2008 | 02:51 PM | 1726 | 16 |
| 20620 | 4/21/2008 | 03:42 PM | 4/21/2008 | 05:27 PM | 105 | 44 |
| 20599 | 4/25/2008 | 09:32 AM | 4/25/2008 | 10:33 AM | 61 | 29 |
| 20599 | 4/25/2008 | 11:03 AM | 4/25/2008 | 03:23 PM | 260 | 30 |
| 20599 | 4/25/2008 | 08:11 PM | 4/25/2008 | 09:40 PM | 89 | 268 |
| 20599 | 4/25/2008 | 09:54 PM | 4/25/2008 | 10:25 PM | 31 | 14 |
| 20599 | 4/25/2008 | 11:10 PM | 4/26/2008 | 04:36 AM | 326 | 45 |
| 20629 | 4/25/2008 | 12:06 PM | 4/26/2008 | 08:54 AM | 1248 | 115 |
| 20596 | 4/26/2008 | 02:36 PM | 4/28/2008 | 08:26 AM | 2510 | 105 |
| 20598 | 4/29/2008 | 06:35 AM | 4/29/2008 | 07:36 AM | 61 | 91 |
| 20598 | 4/29/2008 | 09:02 AM | 4/30/2008 | 06:25 AM | 1283 | 67 |
| 20605 | 4/29/2008 | 05:32 PM | 4/30/2008 | 11:46 AM | 1094 | 36 |
| 20598 | 4/30/2008 | 08:44 AM | 5/01/2008 | 07:52 AM | 1388 | 139 |
| 20598 | 5/01/2008 | 09:10 AM | 5/02/2008 | 05:07 AM | 1197 | 78 |
| 20605 | 5/01/2008 | 03:53 PM | 5/02/2008 | 07:10 AM | 917 | 110 |
| 20598 | 5/02/2008 | 08:12 AM | 5/02/2008 | 08:33 PM | 741 | 185 |
| 20598 | 5/03/2008 | 09:34 AM | 5/04/2008 | 07:22 AM | 1308 | 133 |
| 20598 | 5/04/2008 | 08:48 AM | 5/04/2008 | 12:03 PM | 195 | 86 |
| 20598 | 5/04/2008 | 02:15 PM | 5/04/2008 | 04:06 PM | 111 | 56 |
| 20605 | 5/02/2008 | 08:24 AM | 5/08/2008 | 10:11 AM | 8747 | 74 |
| 20605 | 5/08/2008 | 12:17 PM | 5/08/2008 | 01:13 PM | 56 | 56 |
| 20605 | 5/08/2008 | 01:45 PM | 5/08/2008 | 02:26 PM | 41 | 19 |
| 20605 | 5/08/2008 | 03:27 PM | 5/08/2008 | 04:41 PM | 74 | 35 |
| 20605 | 5/09/2008 | 04:48 AM | 5/09/2008 | 06:51 AM | 123 | 29 |
| 20605 | 5/09/2008 | 09:43 AM | 5/09/2008 | 10:16 AM | 33 | 85 |
| 20605 | 5/09/2008 | 10:57 AM | 5/09/2008 | 11:27 AM | 30 | 26 |
| 20605 | 5/09/2008 | 02:08 PM | 5/09/2008 | 03:28 PM | 80 | 32 |

**AquaTracker** can perform excursion analysis on a selected receiver or a selected group of receivers (to *multi-select* receivers, use the same technique described for grouping receivers and defining zones).

**Show Excursion** is part of the Receiver Context menu. Thus, in order to show this option you most first place the mouse pointer over a receiver and then right-click on it. Once you select **Show Excursion**, **AquaTracker** will prompt you for two thresholds needed for the analysis:

***Minimum Excursion Time***: If the fish leaves the receiver (as last detection) for *less* than this time, **AquaTracker** will assume the fish is just coming in and out of the receiver range. If the fish leaves for a time longer than this threshold, the excursion is counted. Keep in mind that the fish has to return in order for an excursion to be counted. Otherwise, it is considered a *transit*.


***Residence Threshold:*** This is the minimum residence time a fish has to be detected (as calculated from at least *two* detections) in order to be counted as residing in the vicinity of the receiver. If the fish leaves the receiver longer than this time, its counted as not residing within the vicinity of the receiver. **Note that in order for a fish to have an excursion, it would need a *previous residence*, otherwise the fish simply *transited* through the receiver and no excursion or residence is calculated for the fish.** This is different from the way in which AquaTracker calculated excursions on previous versions.

The following information is included in the excursion analysis:

**Fish ID:** Fish acoustic code

**Start Day/Start Time**: Start day/time of excursion. This is the last time the fish was detected by the receiver.

**End Day/End Time**: End day/time of excursion. This is the first time the fish is re-detected by the receiver.

**Duration**: Duration of excursion in minutes.

**Prev. Residence**: Previous residence time. Time spent around the receiver before the fish left the receiver on its excursion.

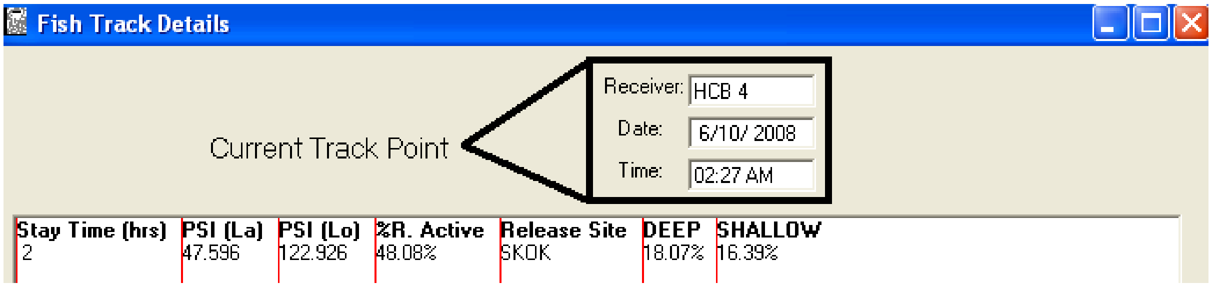
You can export the data in the window by using the **Export…** button.

**NOTE**: *To export the excursions in all receivers.*
*Go to **File→ Export Excursions**.*

# 3.6 Tag Analysis

*Geographic tags* can be assigned to receivers (see section

2.3.1 Receiver Information). For example, if receivers A, B and C are deployed in the shallow area of a reef, and receivers D, E, and F are on the deep reef, and you want to know how much time a fish spent on the deep vs. shallow area of the reef. To do this, assign the SHALLOW tag to receivers A, B and C, and the DEEP tag to receivers D, E, and F.




Once tags are assigned, they will appear on the **Fish Track Detail** window. The tags will also be shown when the track analysis is **exported**.

Tags can be assigned manually (on the **Receiver Information** window) or by using the **Define Geographic Zone** tool on the **Receiver Context Menu**.

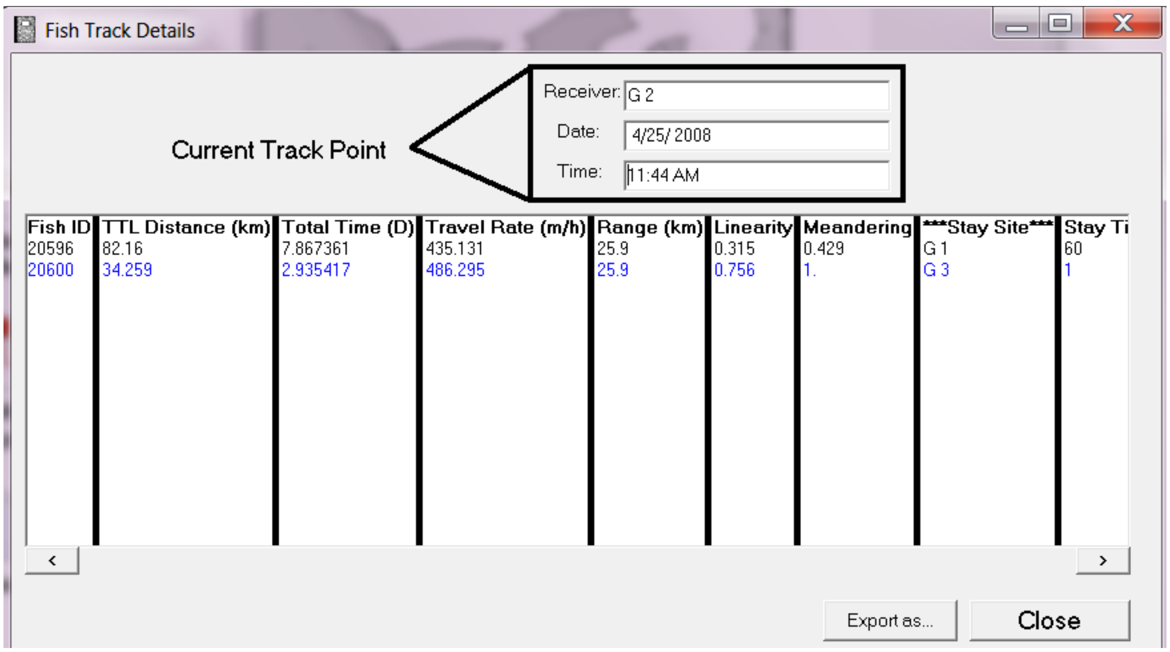
In the example above, the fish spent 18% of the observed time in the DEEP receivers and 16% in the SHALLOW receivers. The remaining 66% was spent in other receivers that had no tag designation.

Geographic tag information is saved in AQN files so once you define a zone, the AQN file will tell AquaTracker where the zone is located in the map.

## 3.7 Analyzing Fish Tracks

Clicking on the **Animate** button shows the **Fish Track Details window**. This window contains details of the "current track point" or the receiver and fish represented in the animation. The window also contains a summary of any previously tracked fish. Note that the information might not be displayed all at once, thus there are page-flipping arrows below the output window. In the example below, clicking on the right arrow will reveal the rest of the analysis, including Stay Time, %RA, PSI La, PSI Long, etc.

Once ***AquaTracker*** finishes showing the fish track animation, it will display the summary statistics for the fish track on the summary window. Clicking **Export as…** allows you to only export the fish tracks shown on the summary window.



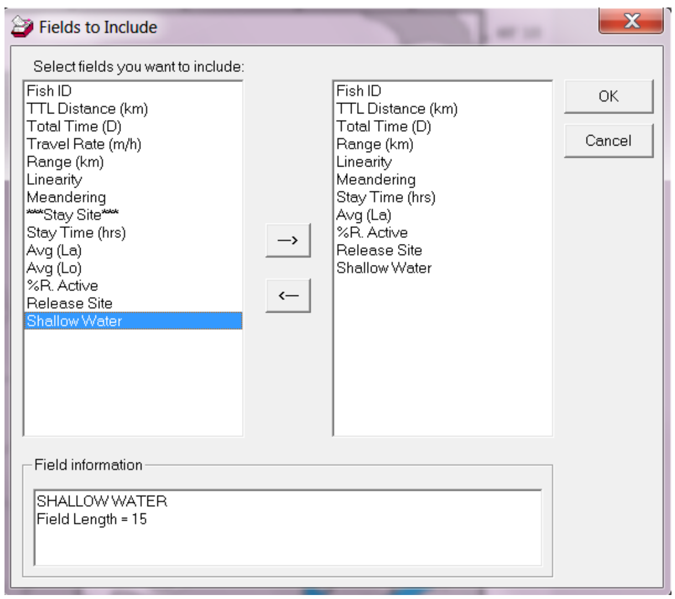

**NOTE**: *Closing the window will not erase it is contents.*

## 3.8 Exporting Track Analysis Data

Track analysis data can be exported in groups using the **Export…** button in the **Fish Track Details** window. Alternatively, all fish tracks can be analyzed at once and exported to a .CSV file (which can be viewed in excel) by going to **File→Expor Data Analysis→Fish Track Analysis.**

## 3.9 Changing what gets exported

You can choose which fields are exported by the program or which fields are displayed in the Fish Track Details window by going to **Options→Select Fields to Show/Export**. As the example on the left shows, fields for tag analysis (e.g. DEEP and SHALLOW) are automatically added here.





Click on the → arrow to include the field. If the field is not already on the list of included fields, it will be added to the list (on the right). Click on the ← to remove the field from the export and analysis. **You can also change the name of the field and change the size of the column** (as its shown on the screen), by double clicking on the name of the field on the list to the left (the list that contains all the fields that can be exported).

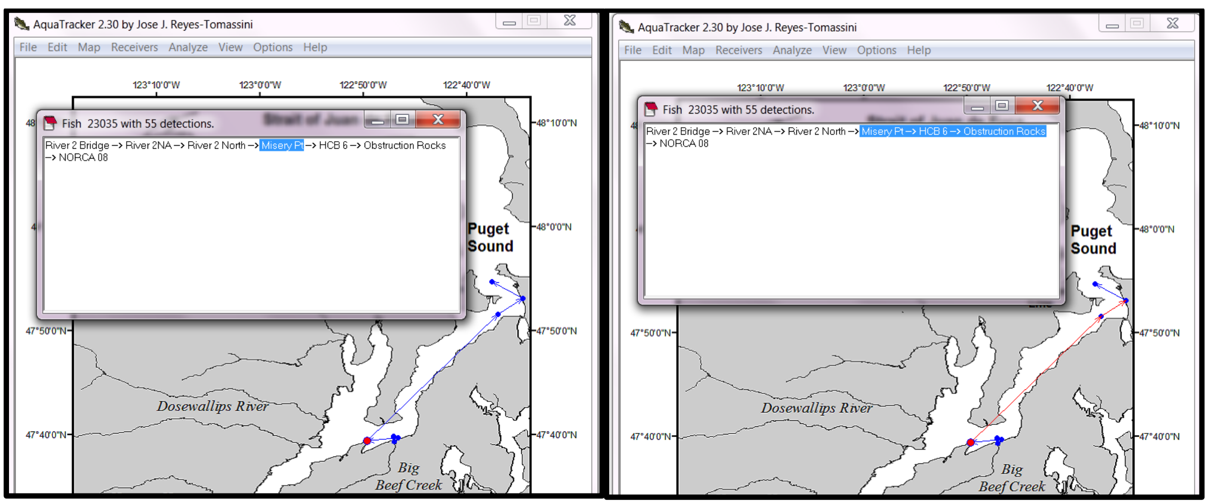
Field information shows the name of the field (in all caps) and the **field length** in characters. You may want to change the field length of the STAY SITE if AquaTracker is truncating the name of your receiver. Similarly, if you use very long fish codes, you may want to change the field length for the FISH ID column. This is also useful if you want to change the separation between columns as shown on screen.

## 3.10 Track Strings

A *track string* is a verbose description of the fish track. The string contains the name of all the receivers visited by a fish in the order the fish visited them, etc. Track points (receivers) are connected by an arrow "-->". Beware that a fish can backtrack and this will be shown by a bidirectional arrow so that the string reads "A<->B" meaning the fish visited receiver B, and then went back to receiver A, then back to B again. With bidirectional tracking there are three possible outcomes denoted by the arrows:

1) Fish went from A to B, back to A, then to B again, then move on to C: A<->B-->C.
2) Fish went from A to B, back to A, then to C: A<->B-->A-->C
3) If the track ends at B, it could be that you will see A<->B at the end. See the example on the text above.

The arrows in the track string will follow the arrows in the map. The **Track String** window allows you to highlight a receiver or a track segment. To do this, select the Track String as you would a text that you would like to copy. <u>The highlighted track or receiver is shown in red by default, but you can change this color by going to **Options→Change highlight color**</u>**.**




The Track String is not exported together with the rest of the fish track data. Instead, it is exported separately. To export Track Strings, you will need to go to **File→Export→Track Strings**. This will export <u>all</u> the *track strings* into a CSV file.

# 3.11 Reference Track: Track Similarity Search using Minkowski Distance

**AquaTracker** allows you to search for fish in the data set which have followed a specific track using a clustering analysis algorithm. The track used as a search query is called the *reference track*. The program calculates the track parameters for the reference track, then using a modified version of a weighted K-Means which uses the Minkowski distance as a parameter in calculating the cluster centroid (de Amorim 2012) **AquaTracker** calculates the distance between each track and the reference. The program finds those fish tracks that are closer in this metric to the reference track. For each fish track in the dataset the following value is computed:

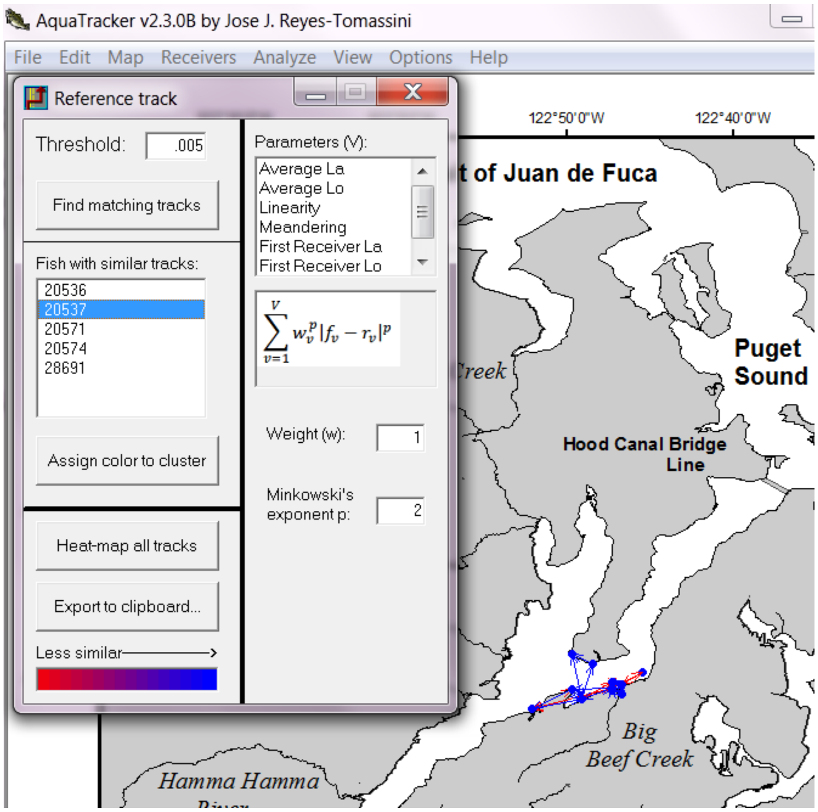
$$\sum_{v=1}^{V} w_v^p |f_v - r_v|^p$$

where, $f_v$ is the fish track parameter $v$, and $r_v$ is the reference track parameter $v$. Each parameter is assigned a *Minkowski exponent*, ***p***, and a weight, ***w***, depending on the parameter's importance in describing the fish track. The researcher can use any of the following parameters: path center, range, ranging index, first detection location, and total distance traveled. You can change both *p* and *w* for each parameter and you can also select a different threshold for the Minkoswki metric calculation. <u>Note that any value of ***p*** less than 1 results in a concave space and are therefore considered invalid values</u>.

There are two ways to use the reference track tool:

1) <u>Use a track from your data as reference track</u>: Select the track you would like to use as reference by selecting it in the **Actions window**. On the canvas, place the mouse over the track and left-click on it to display the canvas context menu. You should see the option to **Set as reference track**. Once you click on this option, the **Reference track** window will be displayed.
2) <u>Create your own (user-defined) track</u>, using the deployed receivers by clicking on the **Draw Reference track** icon in the **Actions** window . The program will show all the receivers loaded in memory. Click on a receiver to set it as your "origin" receiver, then click on another receiver to "connect" them in a track. Keep in mind that some tracks are less linear, and linearity is one of the values considered in matching the tracks. Thus, you may want to add some "ranging" and "tortuosity" to the track in order to mimick a real track.

Once you have selected a track or created a track, click on **Find matching tracks** in the **Reference track** window. This version of **AquaTracker** does not implement a function that finds the threshold (perhaps later version will!), so you will need to play with the "Threshold" setting in order to get a good value for your query. Also you can change the parameters included in the calculation by changing the weights and exponents, etc.




## The Reference Track Window

***Threshold***: This is the cut-off value used to determine if a track belongs to the cluster. After changing this value, click on **Find matching tracks** to apply it to a new search query.

***Fish with similar tracks***: Here you will see the matching tracks. Select any track to display it in the canvas. The original reference track is displayed in red.

***Assign color to cluster***: Click this button to assign a color to the list of fish returned by the search query (above).

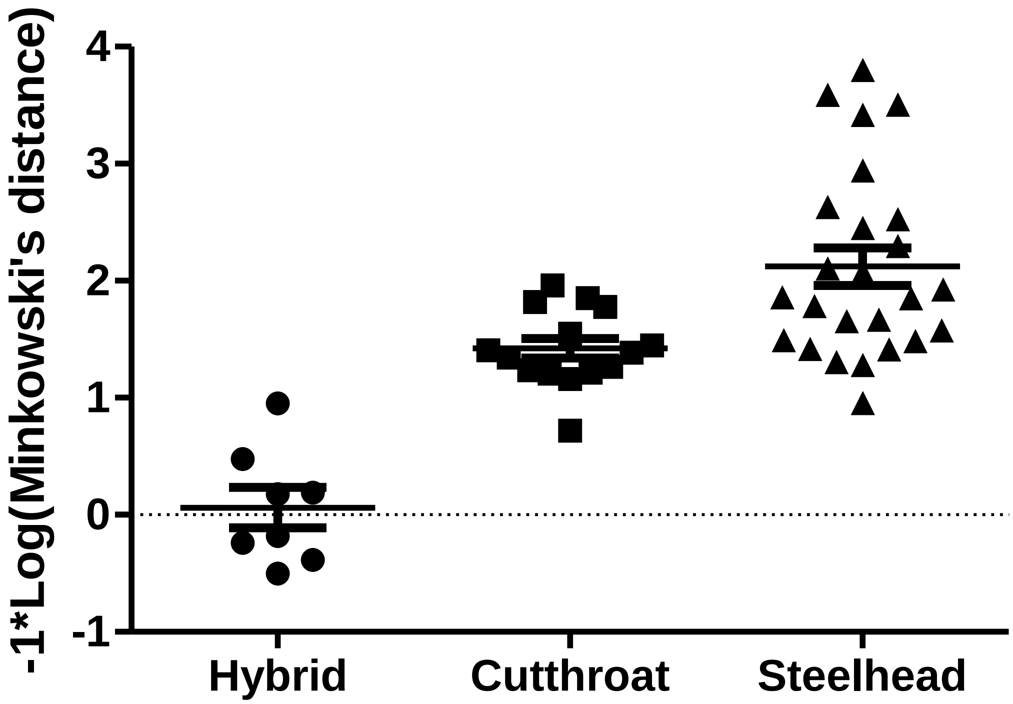
***Heat-map all tracks***: Applies the heat-map shown (red more similar; blue less similar) to all the tracks loaded to memory. This will change the colors assigned to all the fish tracks in memory.

***Export to clipboard***: This option allows you to copy the tracks in memory to the clipboard. The program will include the track number and the Minkowski distance calculated for ALL the tracks in memory. Use this option to generate a graph such as the one in the following page.

***Parameters***, ***Weight*** *and* ***Minkowski's exponent***: Select the parameters, weight and exponent included in the calculation of the Minkowski Distance. The parameters available are:

> *Average La/Lo*: Average lattitude of the track (i.e. track center)
> *Linearity*: Track linearity
> *Meandering*: The meandering index as calculated by the program
> *First receiver La/Lo*: Coordinates of first receiver in the track (origin of track)

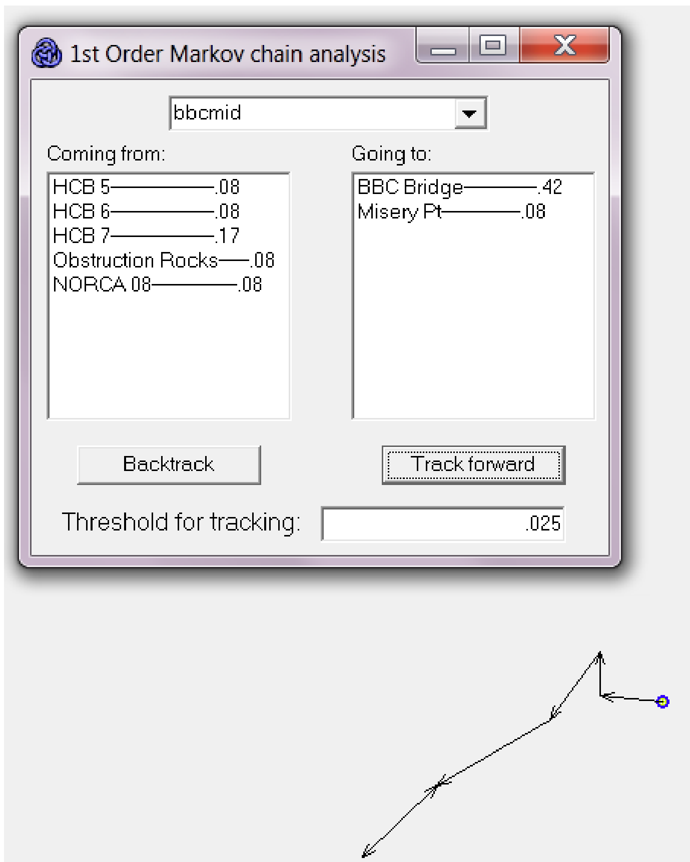
*Total distance*: The total length of the track




Using the "Export to clipboard" function of the **Reference Track** window, we have created a graph illustrating some key differences in the movement metrics between three populations of trout inhabiting the Hood Canal and Puget Sound. The reference track used to calculate the Minkowski distance was a linear track leaving Hood Canal and entering Puget Sound without delay. The interpretation of this particular graph is complex, but to understand the underlying behavior of each population and the context of the graph see Moore et al () and Reyes-Tomassini et al. ().

# 3.12 $1^{st}$ Order Markov chain analysis

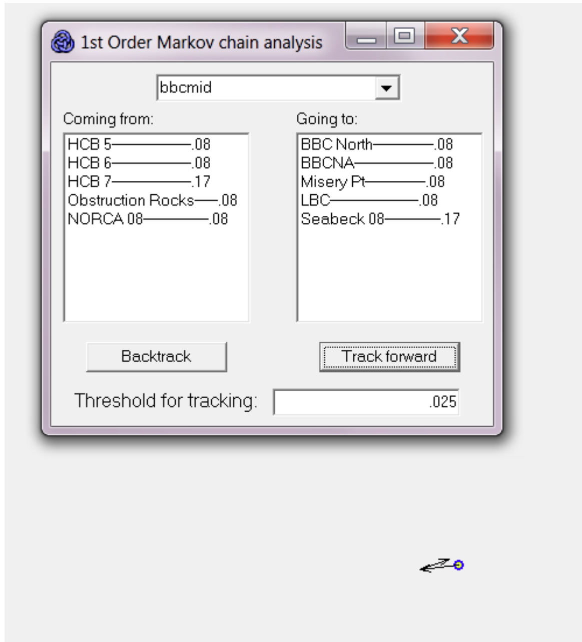
**AquaTracker** offers a simple Markov-chain analysis tool to explore the movement of fish from one receiver to another. This tool is one that the author wishes to develop further and is provided in this version as an experimental tool. The tool calculates the forward probability of going from one receiver to the next, or the reverse probability of having come from one receiver upon visiting another. The probabilities are calculated by simply dividing the number of detections made by a fish going from receiver $R_1$ to $R_2$ by the total number of detections in receiver $R_1$ and vice versa. To use this feature go to **Analysis→Markov chains**. The Markov Chain Analysis window will pop up. The probability estimate (based on the real data) is given to the right of the receiver name.



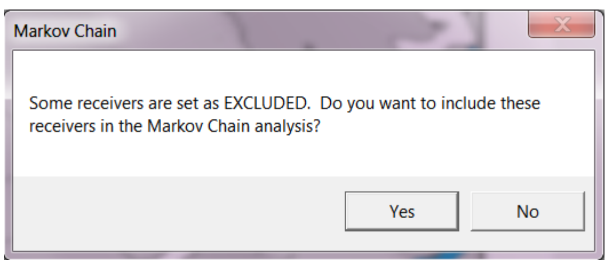

To display the forward chain (going from the receiver selected), click on **Track forward**. To display the reverse chain (going to the receiver selected), click on **Backtrack**. The receiver with the highest probability is always selected as the next in the chain, unless the probability is less than the *threshold for tracking*, in which case the chain ends.

You can also change the composition of the chain by excluding receivers at the top of the list, go to **Edit→Exclude from analysis→Receivers**.

For example, excluding BBC Bridge changes the above chain and creates a very different looking path from the bbcmid receiver:




When only one fish is displayed in the canvas or if some of the receivers are already set to excluded, you may get this message:




AquaTracker is simply warning you of the effect of choosing to analyze the chain generated when receivers are not included.

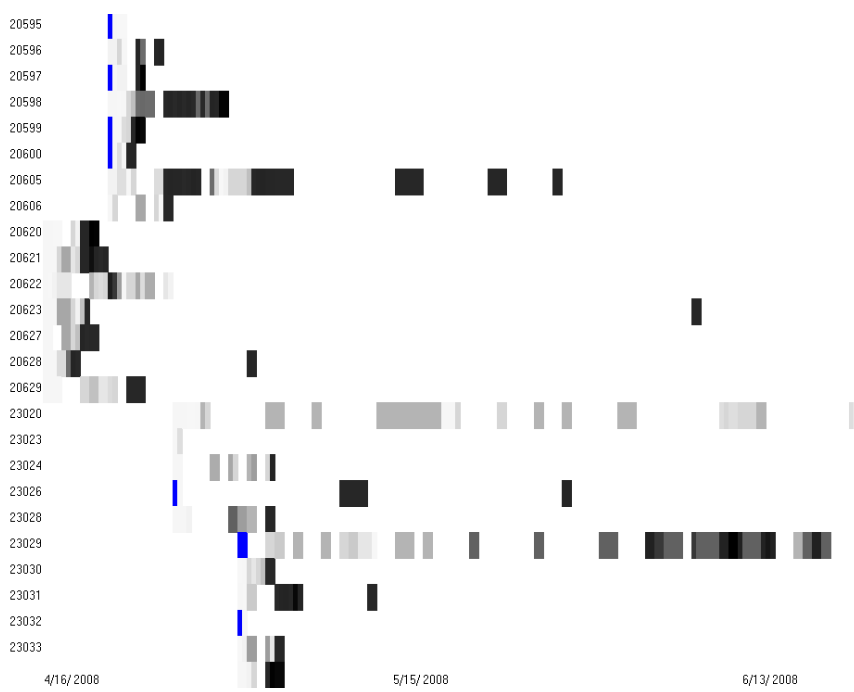
The 1$^{st}$-order Markov Chain generated by AquaTracker is a one-state model chain. Future versions of **AquaTracker** will implement higher-order Markov Chains with at least three states (fish stays in receiver, moves to a new receiver, or goes back to a visited receiver) as well as Markov-chain classification of a fish path.

Keep in mind that the program suggests a threshold based on the number of receivers, but its likely that this threshold is underestimated. A **random-walk** algorithm is probably needed here. The next version of AT released may expand this analytical tool. For now, keep in mind that the topography of the array influences the probability that the movement of a fish from one receiver to the next is random or not random and that the model does not take residence into consideration.

# Chapter 4: Additional visualization tools

**AquaTracker** most prominent visualization tools are its Show Track and Animate Track tools. However, the program offers a wealth of visualization tools that complement the visualization of a fish individual's track. Among these are tools to visualize the number of pings per receiver in an array, the total fish detected by each receiver in an array, and an option to visualize the spread of the detections across time. This last tool is part of **AquaTracker** advanced tracking options, which allows you to track the fish in *scaled time*. Additionally, you can speed up tracking by using an option that only animates "moves" and does not animate "residence".

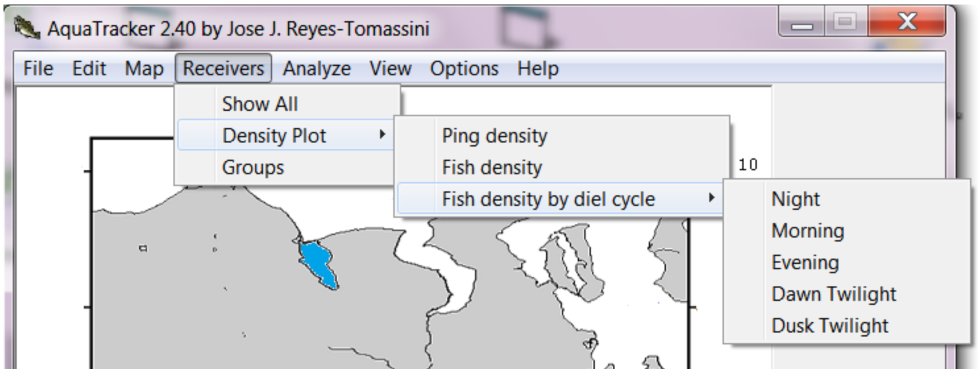
**AquaTracker** can also display a timeline when animating a track with time scaling, a unique tool which allows visualization of the data when detections in a fish track spread over long periods.

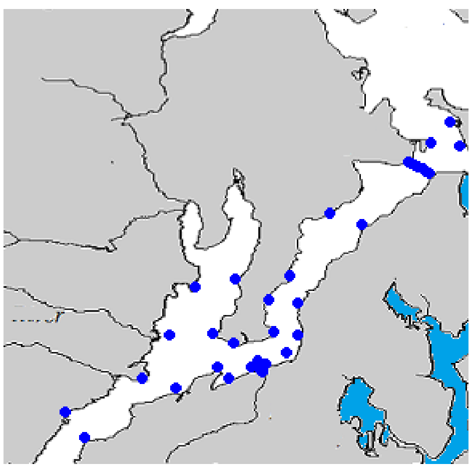



Detection plots combined with a distance heat-map convey large amounts of information in one simple graph. Each fish in the experiment is shown on the Y-axis. On the X-Axis is the day detected. Each "box" represents a detection day for a fish and the color of the box tells you how far the fish is from the release site. The darker the box, the farther the fish is from the site where it was released. The release site is in blue. With a couple of clicks, you can create this graph in AquaTracker in a matter of seconds.

# 4.1 Visualizing Receivers

Receivers can be visualized in **AquaTracker** in various ways. Receiver detections can be shown as color-scaled heat-maps in which the color intensity of the marker is correlated with the number of detections. The receiver menu has 3 choices:

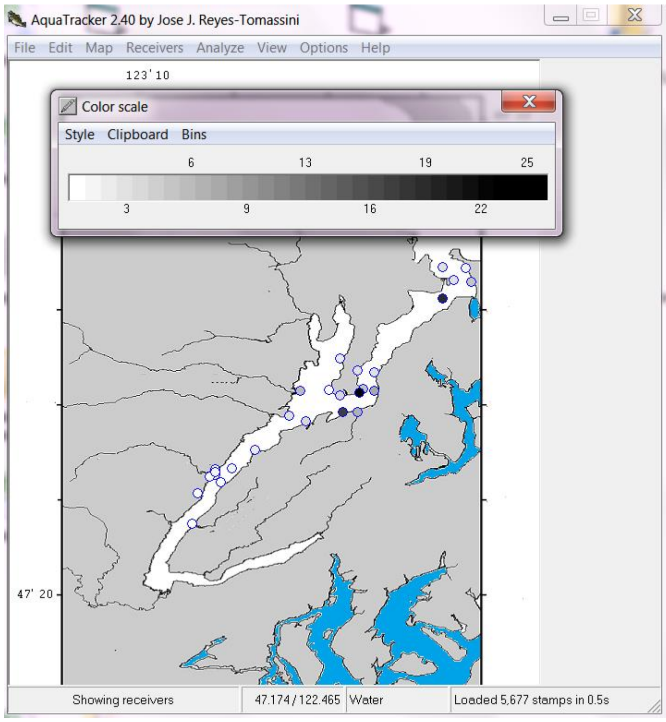


**Show all**: Shows all the receivers for which detections exist in the fish track selected in the actions window or, if you have selected to show ALL the tracks, all the receivers loaded in memory. Grouped receivers are shown as a single receiver. You can move your cursor over the receiver to see the name of the receiver displayed on the status bar below.

**Show density:** Shows the **density of detection** as a *heat map* by pings, number of fish, number of fish at different times of day (day, night, twilight,etc.). A color scale window will appear on screen, which will show you the color scale used to represent each receiver.


The **Bins** menu on the **Color Scale window** allows you to change the number of bins and the maximum value plotted. The **Style** menu allows you to change the type of color scheme used.



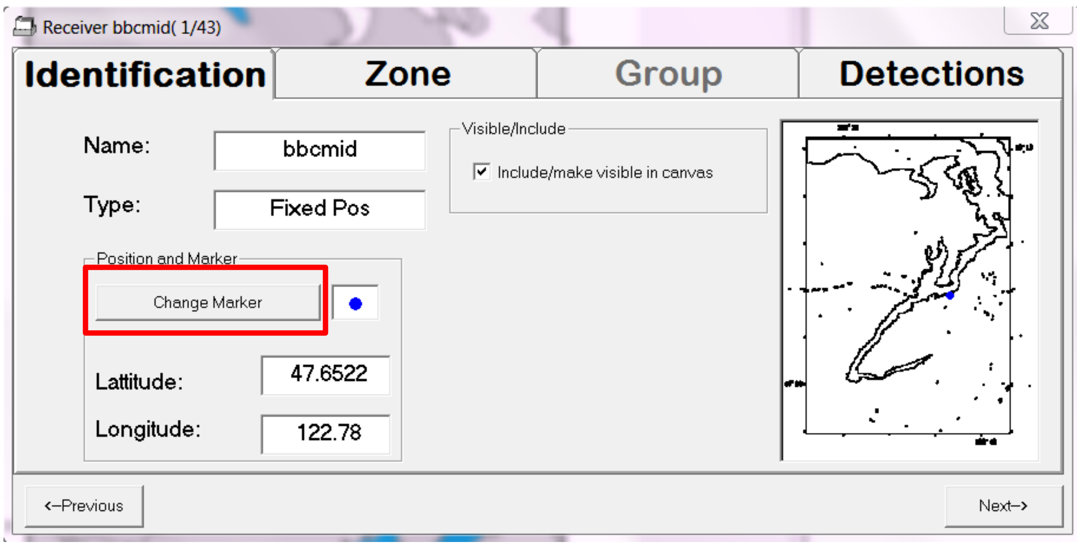

**Hint:** The color scale is interactive. By moving the mouse over the color bins on the color scale window, you can highlight the receivers that fall on that color range and see the number range for that bin. By left-clicking on the scale, you can copy and paste the scale into a document or power point presentation. For more information about the color scale window in **AquaTracker** see 4.6 The color scale

**Groups**: From the Groups option in the receiver menu you can edit and view receiver groups. For more information on *receiver groups* see 3.2 Grouping Receivers

## 4.2 Detection Scatter Plot

Often, you might be interested in the general pattern of movements of fish that occurs in an array. One way to visualize these movements is to use a *detection scatter plot*. In a detection scatter plot, the detections from a single receiver or a group of receivers, are shown on the Y axis, while the day of detection is shown on the X scale. Each receiver or group of receivers can be assigned a color. A detection scatter plot works better when grouping receivers or when used in conjuction with a *distance-based heat map* (see below).

Before plotting the receivers, first select a receiver or a receiver group, then click the left button on your mouse to display the **Receiver Context Menu**, then select **Receiver Information**. Make sure you are on the **Identification** tab, then on the Position and Marker, section click on the button **Choose marker**.

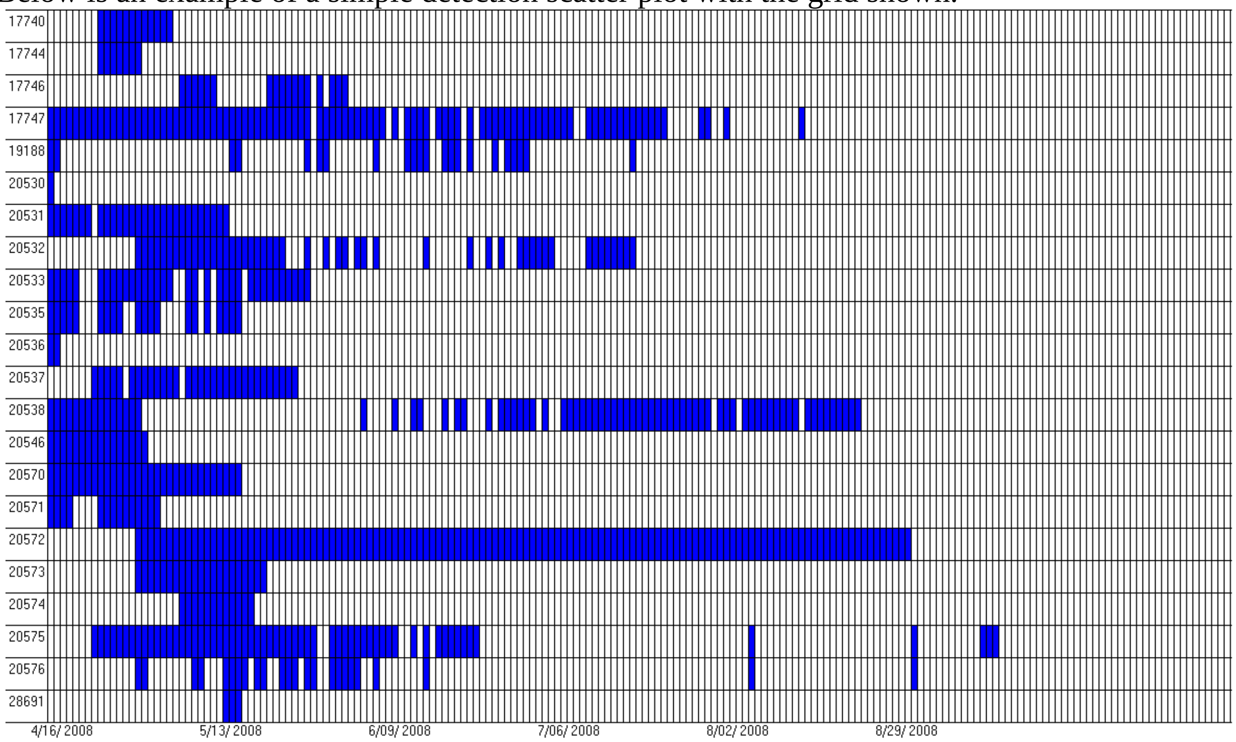



After assigning colors to all the receivers as needed go to **Analyze→Detection Plots**. If the dataset is very large, the program will take a few minutes to process the data. The status bar on the bottom of **AquaTracker**'s main window will display some information about what the program is doing (e.g. "Reading Stamps").

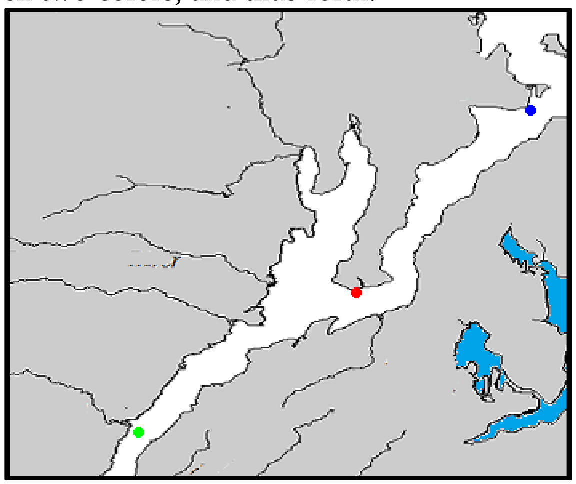
Once the plot is shown, use the scrollbars to scroll throught the plot. You can also adjust the size of the window to increase the portion of the plot shown. <u>The program will automatically adjust the size of the markers in the plot and will also show or hide the axis labels, depending on the size of the window</u>. Moving the mouse over any of the markers will reveal what fish was detected in that date, the date of the detection, the receiver that the marker represents, and the group it belongs to.

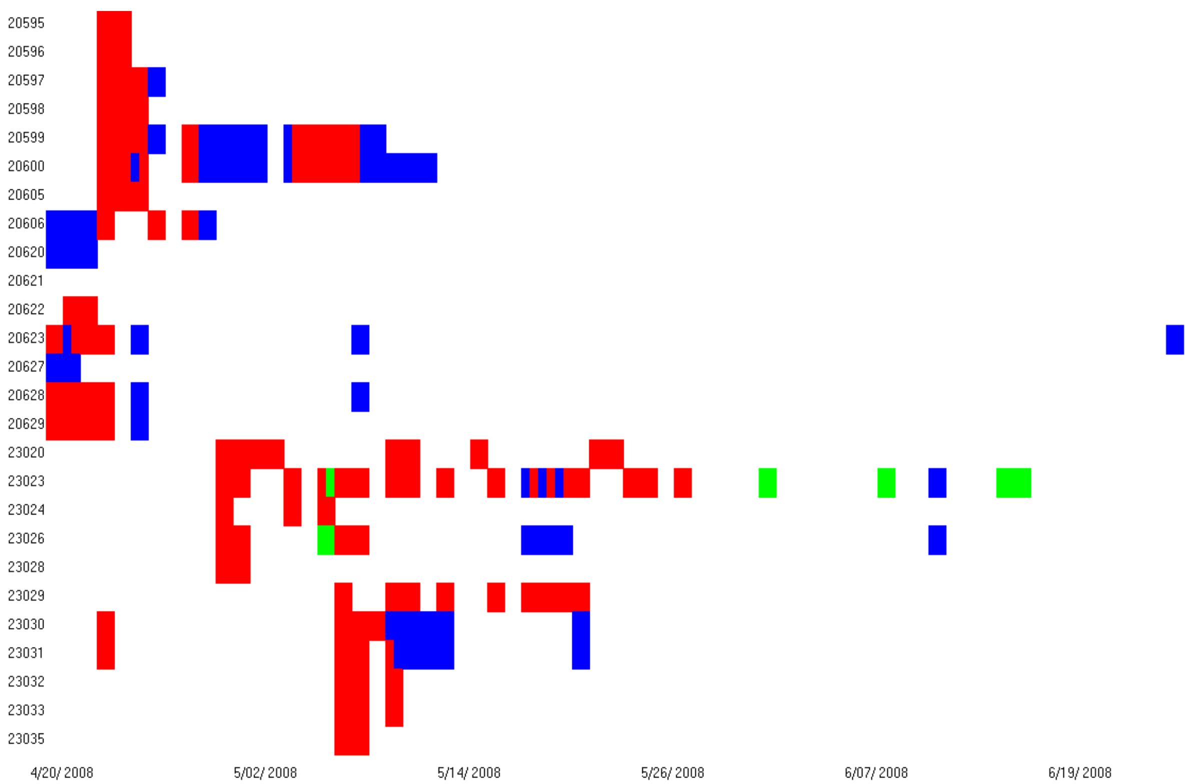

You will notice that when you mouse over any of the receivers in the plot, all the plot points belonging to that receiver will be highlighted in the graph.

You can now show the grid lines in the plot by right-clicking anywhere in the graph and selecting and unmarking **Grid→Hide grid**. By default AquaTracker is set to hide this grid. Below is an example of a simple detection scatter plot with the grid shown.



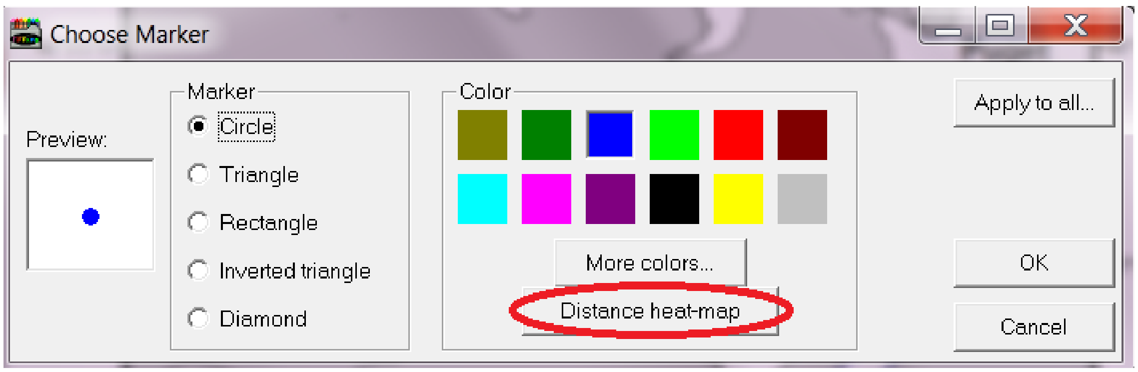
Below is a plot in which the northern (blue), central (red), and southern (green) receivers were grouped together and groups were assigned markers with different colors. Each cell in the graph represents a day and when a fish spends most of the day in one receiver, its assigned the cell gets that receiver's marker color. If part of the day is spent in one receiver and part of the day in another, then the cell is given two colors, and thus forth.



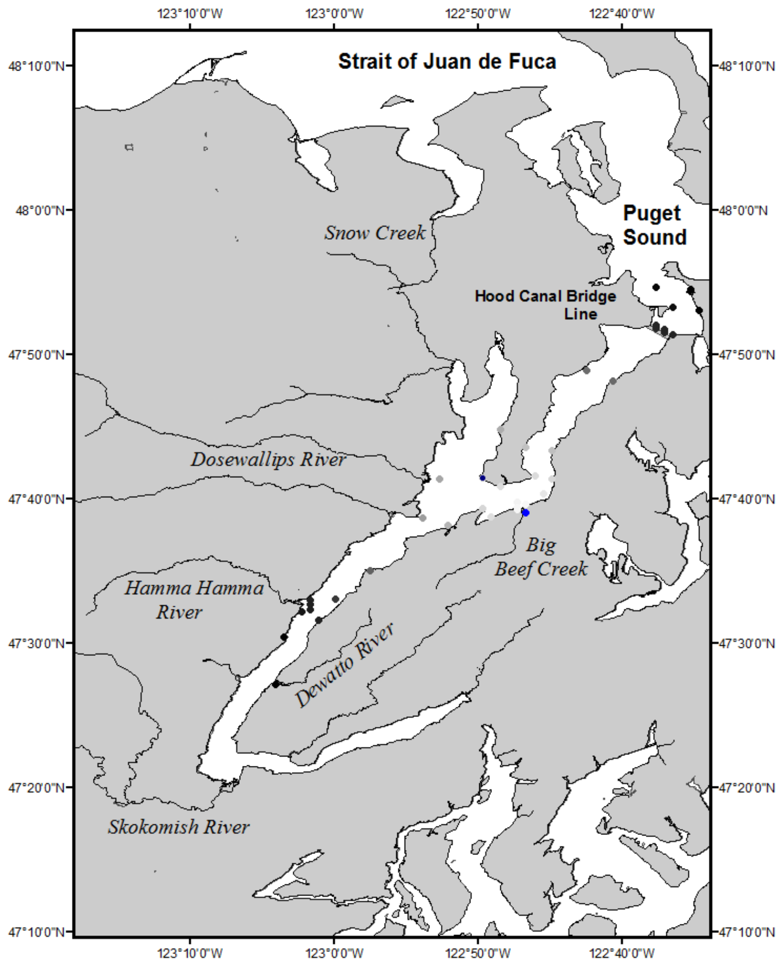


## 4.3 Detection Scatter Plot with distance-based heat map

How can an entire experiment worth of data be summarized in one graph? When combined with the *distance-based heat map*, the detection scatter plot becomes one of **AquaTracker**'s most powerful tools. A distance-based heat map is a color-intensity scaled representation of the distance between all the receivers and a single point of origin. The point of origin has to be a receiver, usually the "release site" but it can be a specific migratory target or a receiver deployed in some region of interest. To create a distance-based heat map, first left-click on the receiver that you want to choose as the point of origin, the select **Receiver Information** and on the Position and Marker section click on the **Choose Different Marker.** On the **Choose Marker** window, click on **Distance heat-map**. The program will then query you to make sure that you want to override any colors previously assigned to the receivers. Choose **yes** to create the distance-based heat map.




The "origin" receiver is automatically assigned the color blue. The fartherst receiver is assigned the color black. Lighter shades of grey are assigned to receivers closer to the origin receiver. In the following page you can see what a typical heat-map looks like followed what the detection scatter plot looks when it is distance-based.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47°40'0"N
47°30'0"N
47°20'0"N
47°10'0"N
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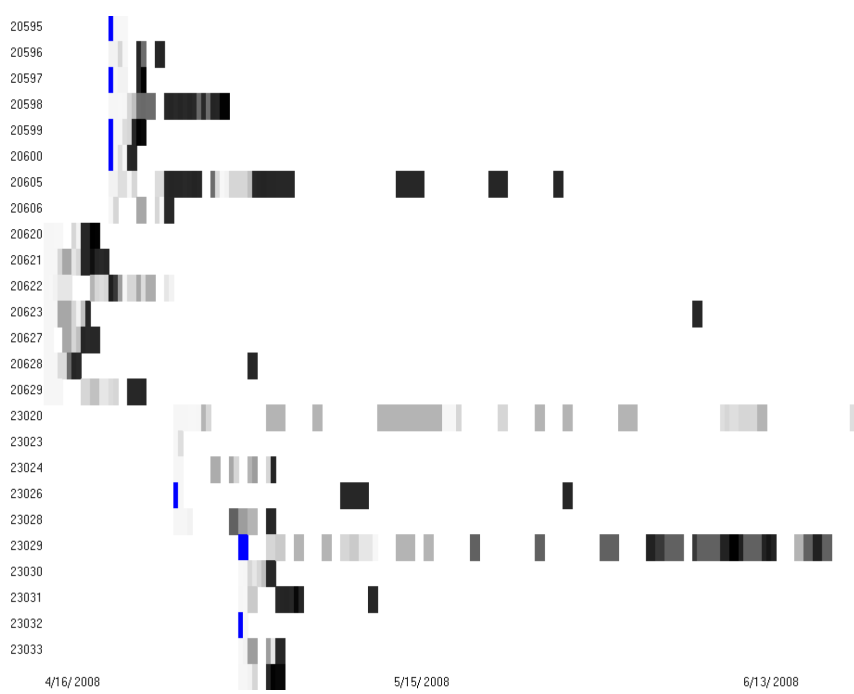
Puget Sound
Snow Creek
Hood Canal Bridge Line
Dosewallips River
Big Beef Creek
Hamma Hamma River
Dewatto River
Skokomish River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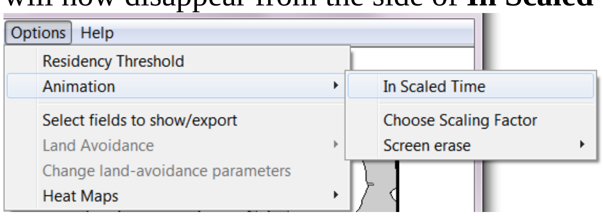
## 4.4 Tracking in scaled-time and the Detection Timeline window

A track usually occurs over a span of several days or even weeks. When tracks are displayed in a map, the sense of time elapsed between detections cannot be conveyed. To visualize the time elapsed between detections, **AquaTracker** allows you to display the track animation in *scaled time*. Since no user will sit in front of the computer for weeks waiting for the next detection to be displayed, showing the tracks in real-time is preposterous! However, computer software magic allows us to scale the time so that for every second that elapses in real time, 1 hour or more can elapse in "track" time. This is the basis for time scaling.

<u>The default setting is 60 milliseconds of real time for every 30 minutes of track time</u>. Thus, under this setting one hour equals 0.12 seconds of real time. In one second of real time, approximately 9 hours elapse in track time. Animating a fish track lasting 30 days can be done in less than 2 minutes! This is achieved without sacrificing a sense of time for each passing day: a user will observe a little more than 2 seconds have elapsed between track days and will be able to "sense" when the fish has not been active for several days or if the fish displays continuous activity throughout the entire track time. Time-scaling the animation in AquaTracker accomplishes one of our design goals: to provide for intuitive data exploration.

By default, animations are always in-sequence. To set animations to scaled-time, go to **Options→Animation→In Scaled Time.** A checkmark will now appear to the left of this option. You can toggle back to in-sequence animation by repeating these steps. The check mark will now disappear from the side of **In Scaled Time**.




To set the time scaling factor to something other than its default, go to **Options→Animation→Choose Scaling Factor.**

**Hint**: If the scaling factor is set to 0, the program will bypass the timing algorithm. This will accelerate the animation of the timeline to its fastest. However, the fastest overall animation is always achieved when the moves-only option is selected (see 7.1 Animation options).


***AquaTracker*** displays a **Detection Timeline** window when the scaled time option is checked. The window loads when you click the **Animate Track** button. A sample track in the detection timeline window is shown below. <u>Each vertical red line in the timeline represents a track day. Vertical black lines represent detections.</u> If any detection occurs around the start of the day, a vertical black line may be drawn over the red line during animation.

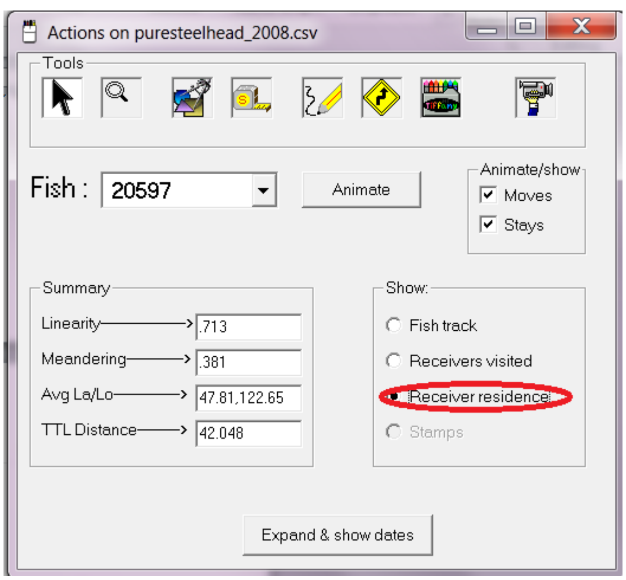
## 4.5 Receiver Residence Time

Sometimes the important question is not how the fish moved in the array but where it spent the most time. To analyze this aspect of the data, **AquaTracker** offers a tool to display the *residence time* of fish at different receivers. The *residence time* is defined as the total time spent moving around the vicinity of the receiver. The formal definition for this function is:

$$R_n = \sum_{i=0}^{N} f(t_{i+2}, t_{i+1})$$

Where $f(t_1, t_2) = \begin{cases} 0, & t_1 - t_2 \geq T_{threshold} \\ t_1 - t_2, & t_1 - t_2 < T_{threshold} \end{cases}$

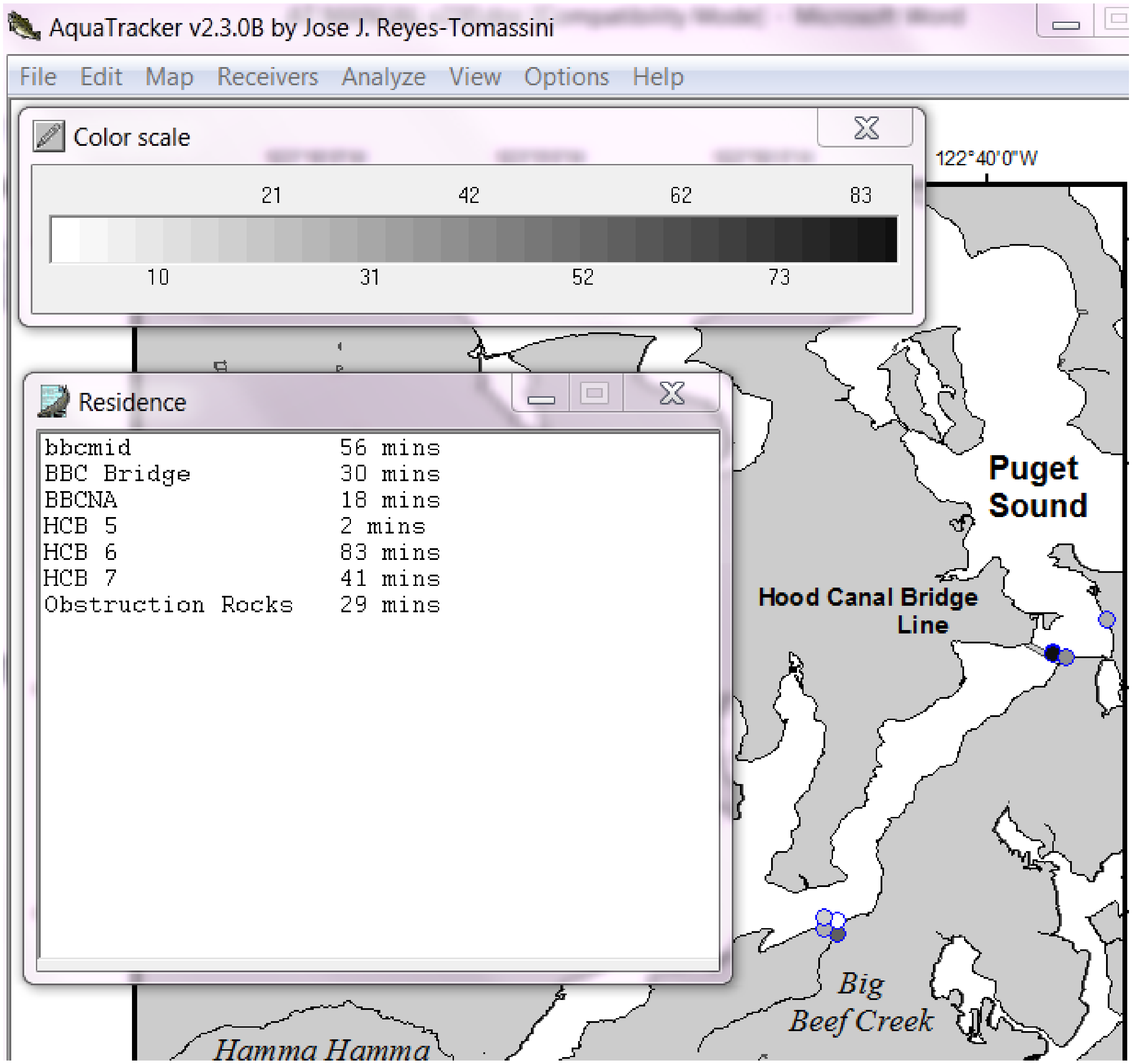
Thus when the time between the last two detections for the fish in the receiver exceeds the threshold, the residence time is not added. However, if the time between the last two detections is less than the threshold, then the difference between the two time points is added.




To show the residence time for the receivers in the track, you will need to select to *show* **Residence Time** in the **Actions window**.

***AquaTracker*** calculates the residence time in minutes. You can copy and paste the residence time data by left-clicking on the **Residence** window and choosing Copy Data. As with **Detection Density Plots**, the **Color Scale** window is displayed. You can highlight the receivers that belong to each time bin by moving the mouse over the color scale. To change the scale parameters, go to **Options → Heat Maps.**

**Hint**: You can change the color assigned to each bin on the color scale *individually*. When you click on any of the bins in the **color scale window**, a color selection menu will pop up. Try it! You can use this feature to highlight a receiver in a graph or a presentation slide.



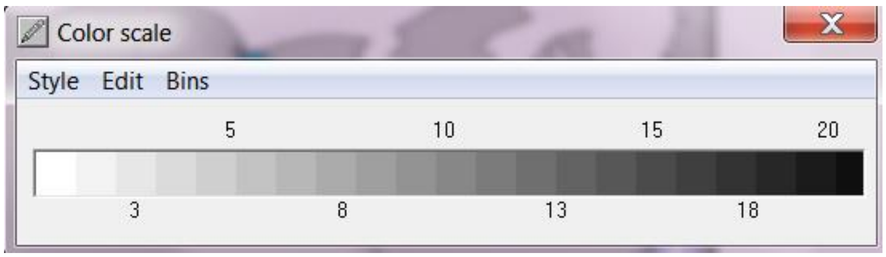

You can display the receiver residence as an animation. The color of the receiver marker will change during the animation of the track to reflect the increase in residence time as the fish moves along the track. The color scale window will pop up. The color scale will allow you to interpret the animation more accurately.

To analyze all the fish tracks and export the results in one step, go to **File→Export Data Analysis→Residence Analysis**.

Eliminating dates from the date list using the date list filtering tool (see 7.5 Filtering data by date ) will change the residence time calculation.

## 4.6 The color scale

The density of detections in a receiver, the residence time, and the distance map are all created using a color scale. Anytime you use any of the features described in this chapter, you will open the **Color Scale** window. This window shows the bins used to create the plot in the canvas. Each bin is assigned a color in the scale.




This window features its own menu bar on top with three menus:

**Style**: This menu allows you to change the color scheme used.

**Edit**: Allows you to copy the image of the color scale to the clipboard so you can use it in a presentation or figure.

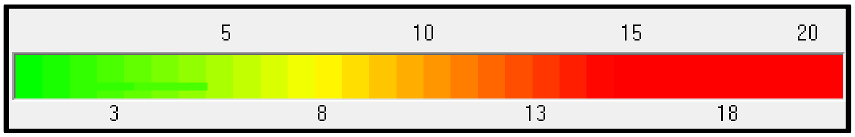
**Bins**: Allows you to change the number of bins and the maximum value used in the color scale.

> **Hint**: Mousing over any of the *bins* will highlight the receivers in the canvas which have been assigned that bins color. When receivers are too close to each other, they may get drawn over. In this case, you can use the *zoom* button in the **Actions** window to reveal the receiver by zooming into the area where the receiver is located.

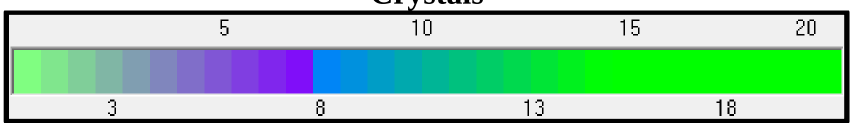
### Style


You can choose between Heat, Crystals, Polar and Grey Scale (default). The **heat** scale uses green as the low-range color, yellow as the middle-range color, and red as the high-range color. The **crystal** color uses a more complex color scheme, which features two tones of green, plus purple and blue. The **polar** scale uses the "cool" colors, with a light blue on the low-range, a dark blue on the middle range, and purple for the high-range. **Grey scale** is the default scale as shown above. Below is a sample scale for each of these color schemes:

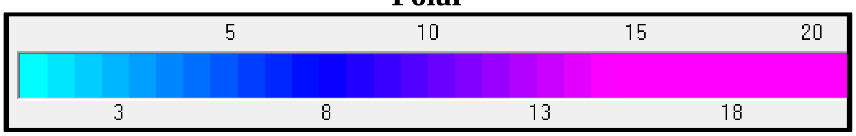
**Heat**




**Crystals**



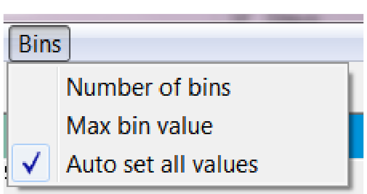

**Polar**




### Clipboard

Copies an image of the color scale into the clipboard so that you can create figures for presentations or publications.

### Bins

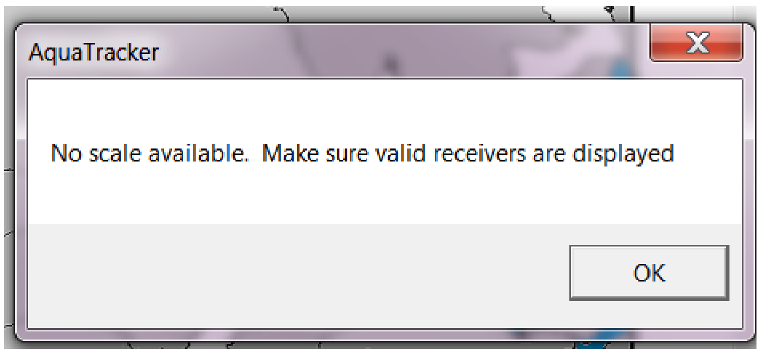



The number of bins is equivalent to the number of shades of color used in the scale. To change this value, go to **Bins→Number of bins**. The maximum value allowed is 254. The default value for this parameter is set to equal the maximum value or 254, whichever is lower. Thus, the program tries to have a 1 to 1 correspondance with the unit (e.g. number of fish or detections) and the bin size. If the range of the scale is outside of 254, the program assigns bins with values higher than a 1 to 1 correspondance.

To change the scale's maximum value go to **Bins→Max bin value**. By changing the value, you can fix the maximum bin value on the scale. Normally, the maximum bin value is calculated by the program each time the scale is used. However, if you want to show two figures in which the actual maximum number of detections is different for each data set, you will need to fix the value. By fixing the value, you will use the same color scale on both figures without having to show a scale for each figure.

Once you change the number of bins or maximum value, the program overrides its automatic calculation of the maximum value and the number of bins. To change this back to default, click on **Bins→Auto set all values**.

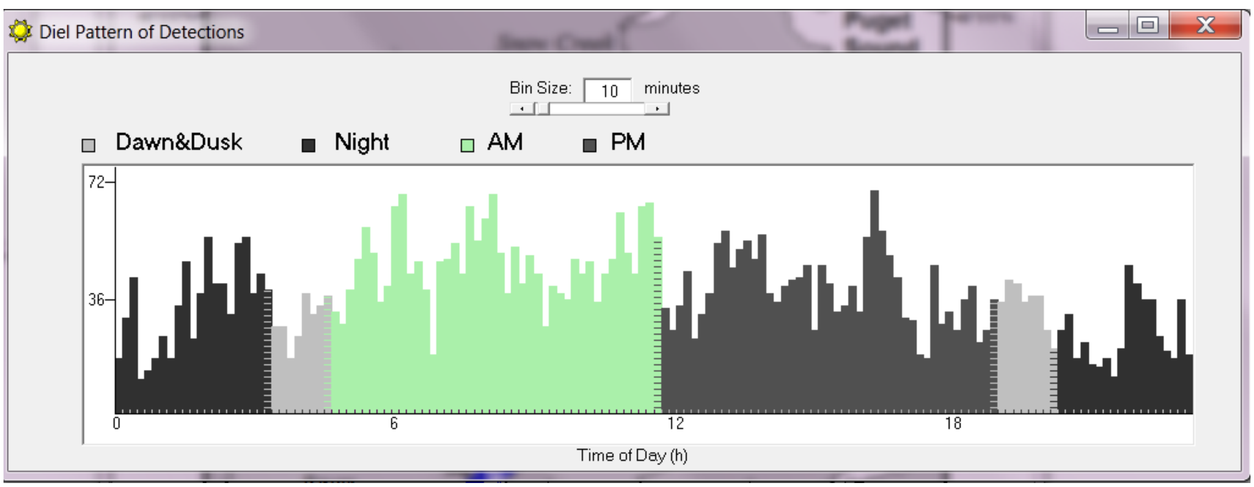
When using the color scale, you may come upon the following message:




This warning is triggered when the plotted values are below the maximum bin value or out of the range of the scale. This can happen if you have entered a max bin value that is too low or when all receivers have the same value and there is no "range" (e.g. all receivers have exactly 1 detection).

# Chapter 5: Correlating animal activity to time-of-day: Diel Pattern Analysis.

**AquaTracker** includes several tools that allow you to analyze the activity of the fish in relation to the time of the day. These tools depend on astromechanical calculations performed using a public-domain program integrated into the software package. Given a precise time and location, the program is able to calculate the position of the Sun relative to the location. **AquaTracker** uses this information to calculate the time of mid-day, dawn, dusk, etc.




This graph shows the movement of the fish in a set of detections as a histogram of time of day. AquaTracker colorizes the bins depending on whether the detection occur at dawn, dusk, at night, etc. Thus, the movement of the fish can be visualized against the actual angle of the sun for the specific time and location of the detection.

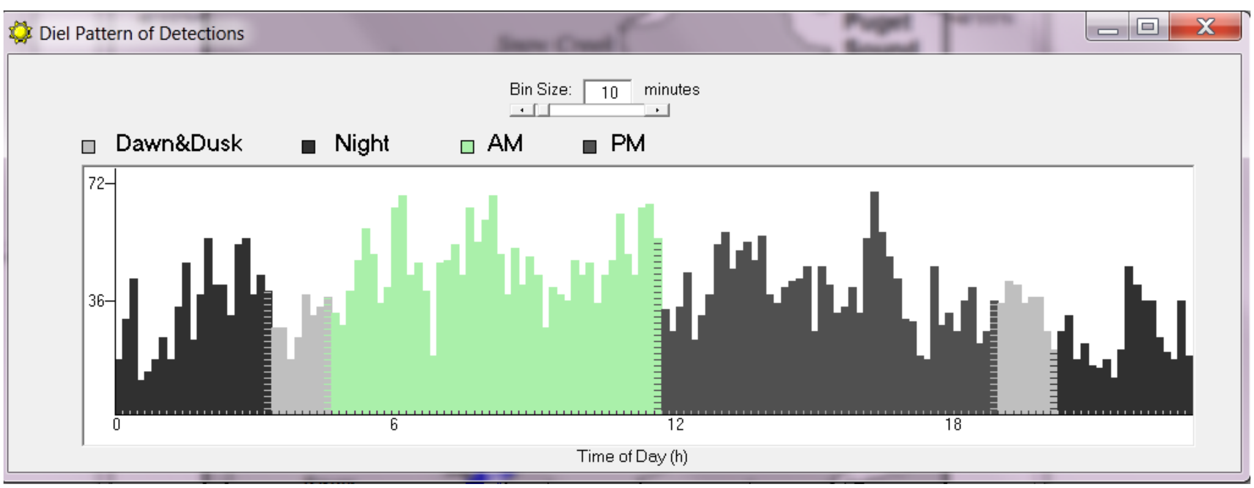
## 5.1 Diel Pattern of Detections

**AquaTracker** can calculate if a detections falls under a specific phase of the astronomical day. It shows this information as a histogram. Based on Beaudreau (2009), **AquaTracker** uses the following definitions for diel-related movement and stay categories:

| Category | Description |
|---|---|
| Dawn | From nautical dawn to sunrise |
| Day AM | From sunrise to the midpoint between sunrise and sunset |
| Day PM | From the midpoint between sunrise and sunset to sunset |
| Dusk | From sunset to nautical dusk |
| Night | From nautical dusk to nautical dawn. |

**AquaTracker** implements an astronomical calculator to find which of these categories a fish move or stay belongs. Note that these are approximations, as the exact time of day for dusk and dawn is dependent on many surface features that are not taken into consideration. To import tables that are specific to the general location of your experiment see 5.3 User-defined Photoperiod.

To show the Diel Cycle Histogram Analysis, go to **View→Diel Cycle Histogram**.



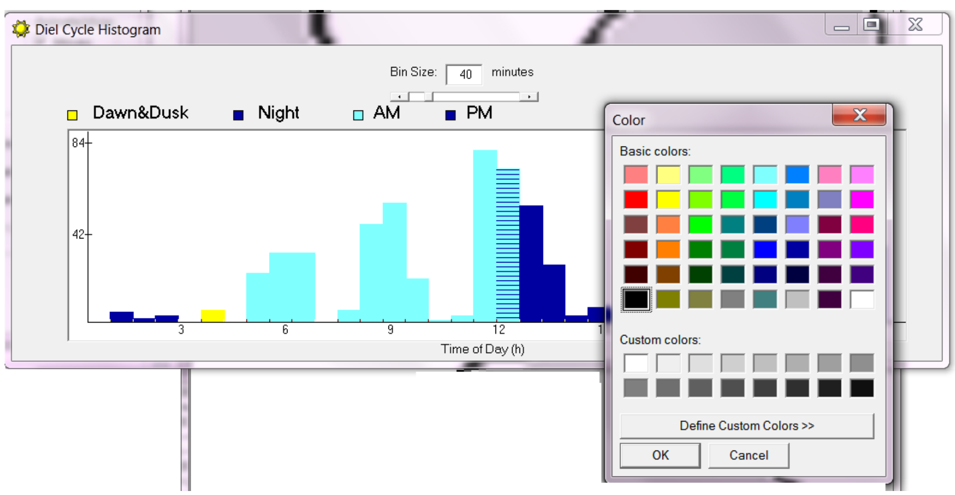

The **Diel Cycle Histogram** window is shown above. The graph starts on the left at 12:01AM and ends at 11:59PM, covering a 24 hour period. The color assigned to each category can be changed by clicking on the category at the top (e.g. "Dawn&Dusk"). The bin size can be changed by using the slider at the top of the window. When a bin falls between two categories, colored lines are drawn horizontally. In the above example graph, the middle of the day is marked by the bar to the left of the number 12 which is filled with green and black lines. Similar transition bins occur between consecutive categories all across the graph. Note that in the graph, the time axis is an approximation and does not constitute an accurate scale. For statistically rigorous analysis, use the clipboard to export the data itself to your preferred statistical analysis program.

When animating the track with this window showing, you will notice that sometimes the bars in the histogram seem to "shrink". This is because the number of detections is increasing in a time-bin. The algorithm then re-calculates the normalization for all the time-bins, causing some of the bars in the histogram to shrink and changing the value of the scale.

When browsing fish tracks on the **Actions** window while the **Diel Cycle Histogram** window is opened, the histogram will be immediately computed and shown.

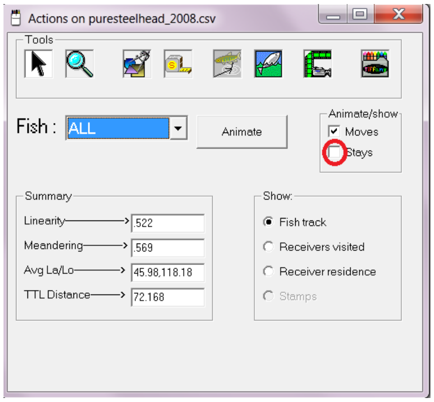
## Changing the color of the bins

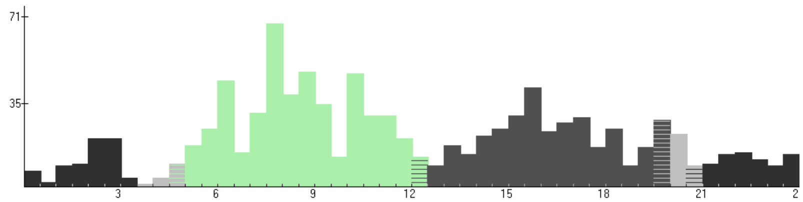
You can change the colors of the bins by clicking on the legend (AM, PM, etc.) on top of the graph. Once you click on the legend, a window will appear with a pallet of colors to choose from. You can define your color by clicking on **Define Custom Colors**.

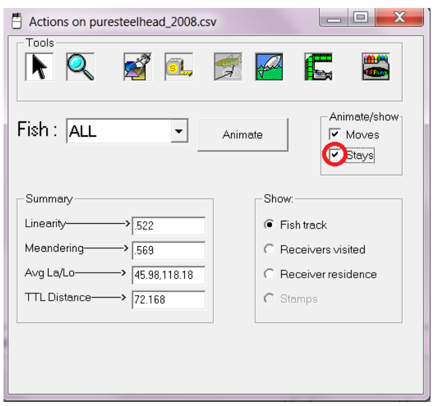


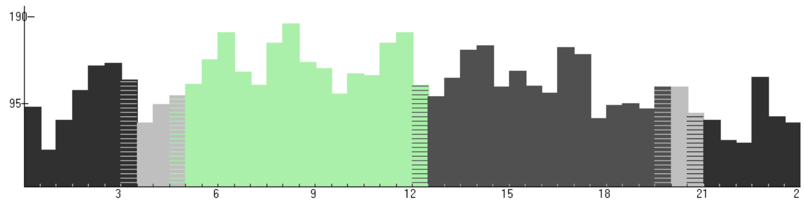
## Moves and Stays

By default, **AquaTracker** shows both moves and stays on the diel cycle histogram. If you would like to only plot detections that belong to moves (arrows in the track), you will need to go to the Actions window and deselect the checkbox marked as “**Stays”**, as shown below:



## Exporting the data in the diel cycle histogram window

The data used to draw this graph can be exported to the clipboard by left-clicking on the graph and choosing "Copy Data" from the context menu. Alternatively, the graph itself can be copied and pasted into a document by choosing "Copy Graph" from the context menu.

The data exported to the clipboard has the following format:

**TIME, COUNTS, PHASE**

Where **TIME** is in 24-decimal hours (e.g. 12:30PM is expressed as 12.5), **COUNTS** are the number of detections for the time bin, and **PHASE** is the name of the phase. If a phase changes within a time-bin, the two phases are shown with the word *and* between them. Time bin 0 in the worksheet below corresponds to detections happening between midnight to 1 am, time bin 1 corresponds to detections occurring between 1 am and 2 am, and so forth.

| Time | Counts | Phase |
|---|---|---|
| 0 | 71 | Night |
| 1 | 63 | Night |
| 2 | 84 | Night |
| 3 | 34 | Night and Dawn |
| 4 | 99 | Dawn and AM |
| 5 | 107 | AM |
| 6 | 127 | AM |
| 7 | 131 | AM |
| 8 | 142 | AM |
| 9 | 104 | AM |
| 10 | 77 | AM |
| 11 | 115 | AM |
| 12 | 154 | PM and AM |
| 13 | 164 | PM |
| 14 | 66 | PM |
| 15 | 81 | PM |
| 16 | 96 | PM |
| 17 | 76 | PM |
| 18 | 155 | PM |
| 19 | 63 | Dusk and PM |
| 20 | 98 | Dusk and Night |
| 21 | 107 | Night |
| 22 | 113 | Night |
| 23 | 43 | Night |

## 5.2 Astronomical Calculations

The astronomical calculator used by **AquaTracker** was originally written in VBA (http://www.bodmas.org/kepler/sunrise_vba.txt), presumably by Keith Burnett, a British physicist. It was extensively modified by the author of **AquaTracker** to conform to the Object-Oriented Programming model. It seems that Keith Burnett took the algorithm itself from Montenbruck and Pfleger's *Astronomy on the Personal Computer*, 3rd Ed.

The following notes are taken from the internal documentation of the algorithm as provided by Keith Burnett:

*"The function will produce meaningful results at all latitudes but there will be a small range of latitudes around 67.43 degrees North or South when the function might indicate a sunrise very close to noon (or a sunset very soon after noon) where in fact the Sun is below the horizon all day. This behaviour relates to the approximate Sun position formulas in use.*

*As always, the sunrise / set times relate to an earth which is smooth and has no large obstructions on the horizon - you might get a close approximation to this at sea but rarely on land. Accuracy more than 1 min of time is not worth striving for - atmospheric refraction alone can alter observed rise times by minutes."*

Internally, **AquaTracker** is set to calculate the nautical twilights for dawn and dusk, as well as the sunset and sunrise. (*Technical note:* To calculate astronomical or civil twilights, the algorithm could be modified per user request.)

**Nautical twilight occurs when the center of the sun is between 6° and 12° below the horizon.** The name comes from the fact that when the sun is in that position, a sailor can't see the horizon any more. Thus, after nautical twilight begins horizon-based navigation is no longer possible. For the purpose of studying animal behavior, it is assumed that crepuscular animals are active after nautical twilight begins and that diurnal animals stop activity around this time.

## 5.3 User-defined Photoperiod

The astronomical calculator can be overriden by using the Abiotic Factor Import function (**File→ Import sunrise/sunset table**). This will allows you to import a file containing the dawn/dusk twilights for each day of the year. A sample table in the required format can be found at:

http://aa.usno.navy.mil/data/docs/RS_OneYear.php.

To create a sample file, just copy and paste the table to the notepad, then save it as a TXT file. It is a –SPACE- separated file. The format is as follows:

```
        Jan.        Feb.        Mar.
Day Rise  Set  Rise  Set  Rise  Set
     h m  h m   h m  h m   h m  h m
01  0727 1657  0715 1729  0641 1801
02  0727 1658  0714 1730  0640 1802
03  0727 1658  0713 1732  0638 1803
04  0727 1659  0712 1733  0637 1804
05  0727 1700  0711 1734  0635 1805
```

**NOTE**: *There are TWO SPACES between days from different months and ONE SPACE between Sunset and Sunrise times.*

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# Chapter 6: Obstacle navigation and land avoidance in AquaTracker

The presence of land masses around an array of receivers increases the chances that a fish track will fall on land, unless the algorithm used to create the track takes such obstacles into consideration. For this reason **AquaTracker** has three land avoidance algorithms. Land avoidance also calculates the *oceanographic distance* from the new plotted track.

1) *Shoreline-based*: This land-avoidance algorithm uses computer vision to analyze the map contour and find the shoreline. It is dependent on the quality of the map you use and it makes no assumptions as to where a fish is more likely to swim to go around the land mass (e.g. there is almost no penalty for choosing the longest path). This algorithm is intended mostly to aid in visualizing tracks.

2) *Fish-corridor*: This land avoidance algorithm also uses computer vision but allows you to create a corridor where the fish track can "snap" to and continue along the land. Thus, this land-avoidance algorithm is a type of user-controlled land-avoidance. When a fish is more likely to go around a specific area than others, you can use this information in the tracking algorithm. This algorithm requires you to draw the path around the receivers.

3) 

*Random-walk*: AquaTracker can implement the shore-based land avoidance as a random walk in two dimensions with a specific persistance parameter. The persistance parameter determines the probability of the walk changing directions. In most animal movement literature this is know as the correlation of the walk. The walk is also set to have a bias: the algorithm plots multiple walks to the receiver and chooses the walk with the shortest oceanographic distance. **Random-walks offer the best solution to land-avoidance**, as the algorithm is relatively fast, reliable, and can be re-plotted to force the program to determine a different path.

## 6.1 Dealing with landlocked receivers

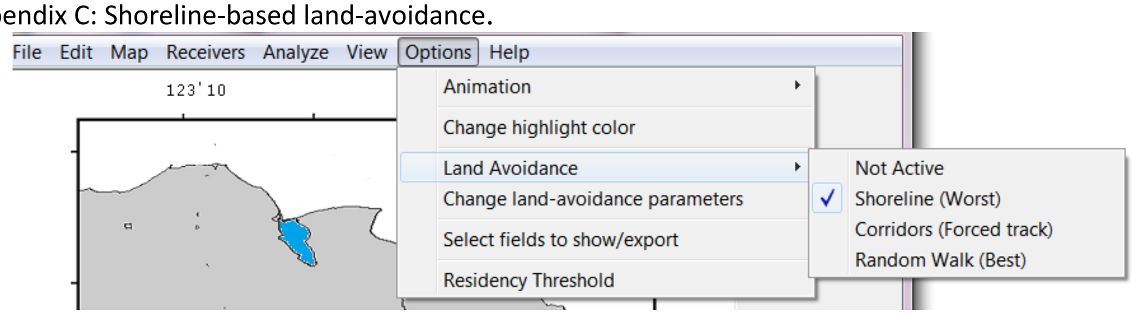
**AquaTracker** approximates the location of a receiver in the map based on your georeference points. Ocasionally, a receiver is located so close to the shoreline or sits right inside a small river delta that the program may think that the receiver is *landlocked*. A receiver is landlocked if there is no clear path to water from any surrounding pixel. To deal with this problem, **AquaTracker** allows you to drag the receiver and move it somewhere else.

To move a receiver simply click on the mouse and while the mouse button is pressed, drag the receiver to any valid location and release the button where you want the receiver to be deployed in the map.

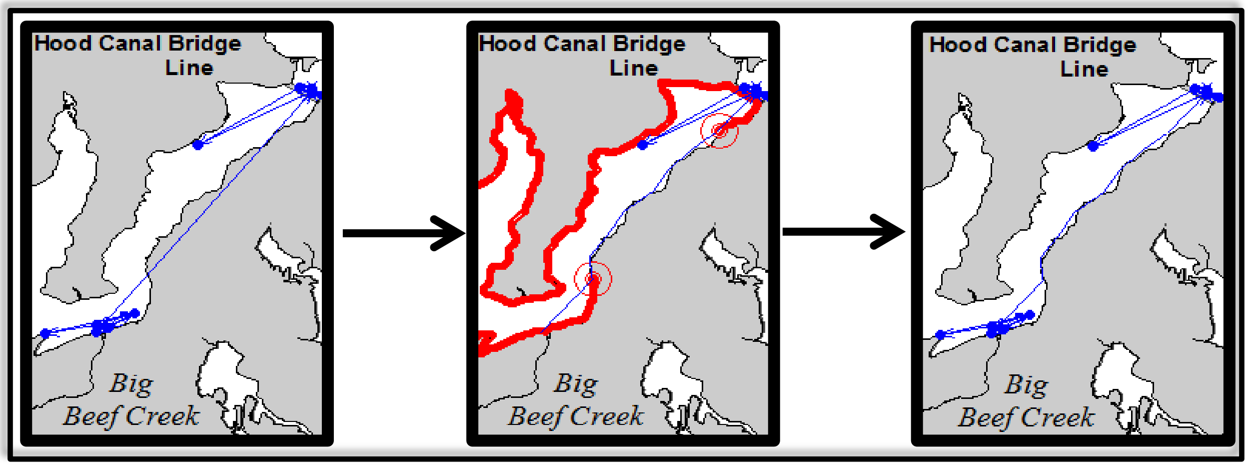

Land-locked receivers are detected automatically and land-avoidance is turned off for the path segment if either of the two receivers (or both) in the segment is land-locked. This is one of the reasons the new AquaTracker is more reliable!

## 6.2 Land-avoidance using the shoreline

**AquaTracker** uses computer vision to "see" the shoreline. To enable shoreline-based land avoidance, first make sure you allow the program to "accept" the map that you are using and that you have told the program what color is the water (1.5 Selecting water pixels (for maps with water as non-white pixels)). You should use a map with a well-defined shoreline and with no gap points along the shoreline. Before loading the map into **AquaTracker**, use an image or photo application to zoom in and carefully look at the pixels in the map contour. Add pixels to eliminate any discontinuity in the shoreline and remove any dithering artifacts created by map-creation software. For further information on this and other issues regarding the map see Appendix C: Shoreline-based land-avoidance.



To enable land-avoidance, go to **Options→Land Avoidance→Use shoreline**. Select ALL fish (or any fish track) in the **Actions** window. If the program sees that a track is going thru land, the land-avoidance algorithm will take over. You will know land-avoidance is taking place when you see red points marking the shoreline as the algorithm scans the map to find the shortest path. The entry and exit points in land are always marked by two red circles as seen below. After the



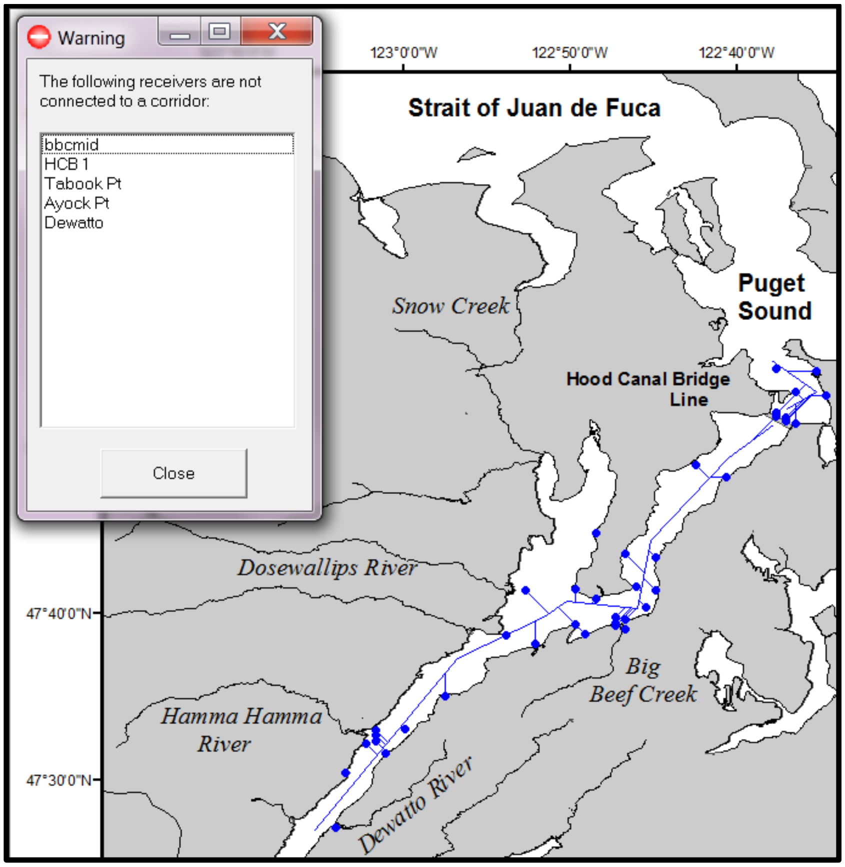

algorithm finishes, re-select the fish to display the results of the shoreline navigation as seen above on the right-most figure. If the algorithm hangs around a point in the shoreline, press the space bar and the algorithm will quit computing a new route. You can look at the path (in red) taken by the algorithm to see if you can find the point its getting stuck at or you can try again using the alternative land-avoidance algorithm (fish corridors).

Keep in mind that the algorithm may take a couple of minutes if you select "ALL" fishes on the **Actions** window. However once the algorithm calculates a new route for a fish track it won't repeat the shoreline scan for that fish. Thus, the algorithm only performs this scan once per fish.

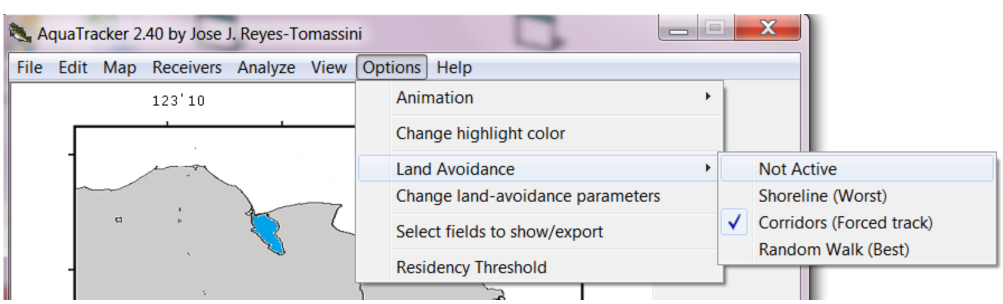
## 6.3 Land-avoidance using fish corridors

***AquaTracker*** allows you to setup fish corridors. To do this you most first draw a valid corridor in the map. Click on the fish corridor icon in the **Actions** window . The canvas won't change, so that you can display whichever track or receivers you want. Thus, make sure the information you need to draw the corridor is already displayed on the canvas (e.g. Show all receivers or show the specific track that is going thru land).

To draw the corridor click anywhere in the map where there is a valid water pixel and move the line drawn across the water where you would like the fish to pass. Once you are done, draw the last segment over any invalid point (land or outside). The line color will change to red to indicate that its now over an invalid region. Click the mouse button once again (while the line is red) and the program will calculate the corridor graph. The graph is a connected graph as seen below. **AquaTracker** will warn if any receivers are not connected (landlocked or not in the vicinity of the corridor). Selecting any receiver in the warning list window will highlight it red.



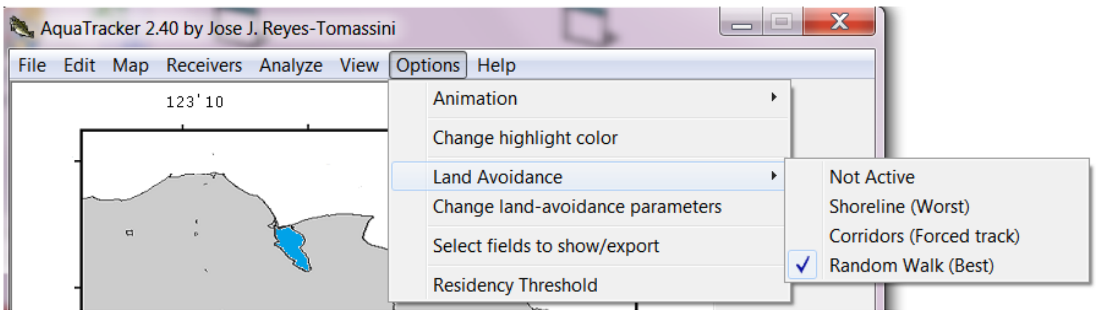

After creating the corridor(s) and connecting the receivers to the corridor(s), you can enable land-avoidance by going to the land-avoidance submenu and selecting fish corridors, **Options→Land Avoidance→Use fish corridors**.

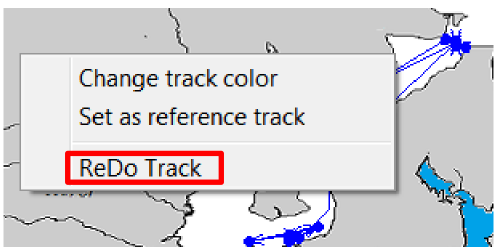



Keep in mind that land-avoidance using fish corridors can result in tracks that may not be what you expect. You can change the calculated fish track by adding a corridor or re-tracing the corridor using a different route. You can also try to move the receiver around the water a little up, down, left or right from its original position.

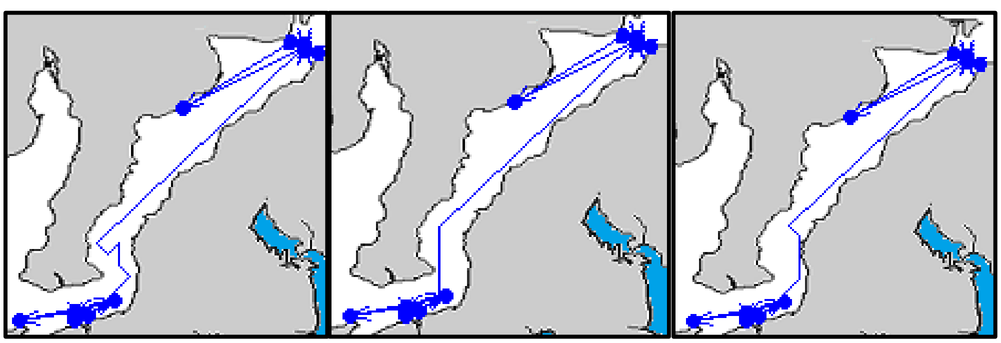
## 6.4 Land-avoidance using random-walks

**AquaTracker** offers a modified version of the shore-line land avoidance in which the fish is allowed to perform a random walk from receiver to receiver in a track segment. As the name implies, there is randomness applied to the solution of these walks. Thus, each time you calculate the route for the same track, the results may be a bit different, even if all else stays the same. This is why the program calculates the walk and can save its results to the AQN file. However, if you are not pleased with the results of the walk for a specific fish, you don't need to quit the program and reload the data. Instead, you can force **AquaTracker** to recalculate a track using **ReDo Track** from the **canvas context menu** (e.g. by right-clicking on the canvas) when the track is displayed.

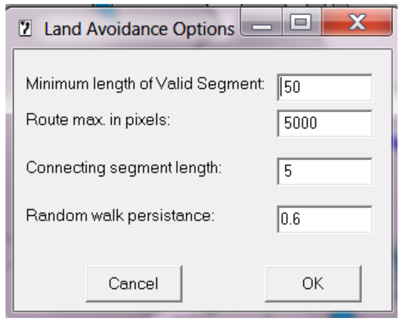



Below are three different paths plotted for the same fish by the random walk algorithm after clicking on the **ReDo Track** option in the context menu. The oceanographic distance calculated for each path is slightly different (not shown). You can see that the first path plotted to the left has more "wandering" than the one in the middle. The one on the right is more shore-oriented, makign it look almost exactly like a shore-based land-avoidance.

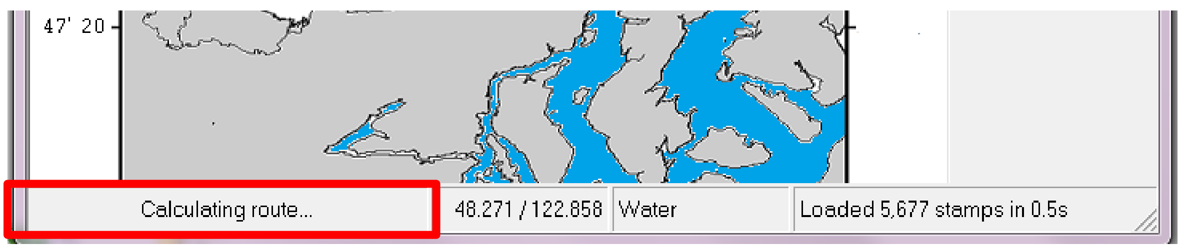


You can change the persistance of the walk by going to **Options→Change land-avoidance parameters.** By default, random walks have a persistence of 0.6, which means that out of every 10 steps in the walk, about 6 of them will be along the same direction unless land is encountered. If land is encountered, it forces the algorithm to change direction regardless of the persistence setting. The highest the value of the persistance parameter is, the more linear the walk will result.



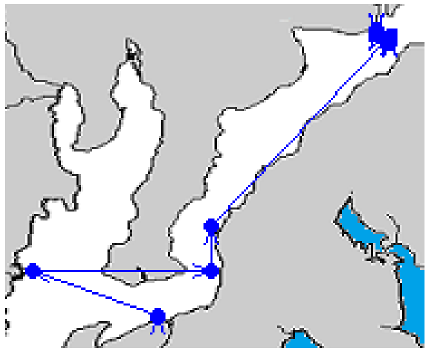

## 6.5 Avoiding frozen screens

Ocassionally, land-avoidance may freeze and the program will seem unresponsive. To re-gain control of the program, you will need to tell AquaTracker to stop calculating the route in which the program is getting stuck. First, look down at the *status bar*, which is the bar located all the way at the bottom of the screen. The status bar is continously updated with program information and the coordinates and receiver ID of where the mouse pointer is located. When AquaTracker is stuck, you will see the words "Calculating route…" on the status bar.

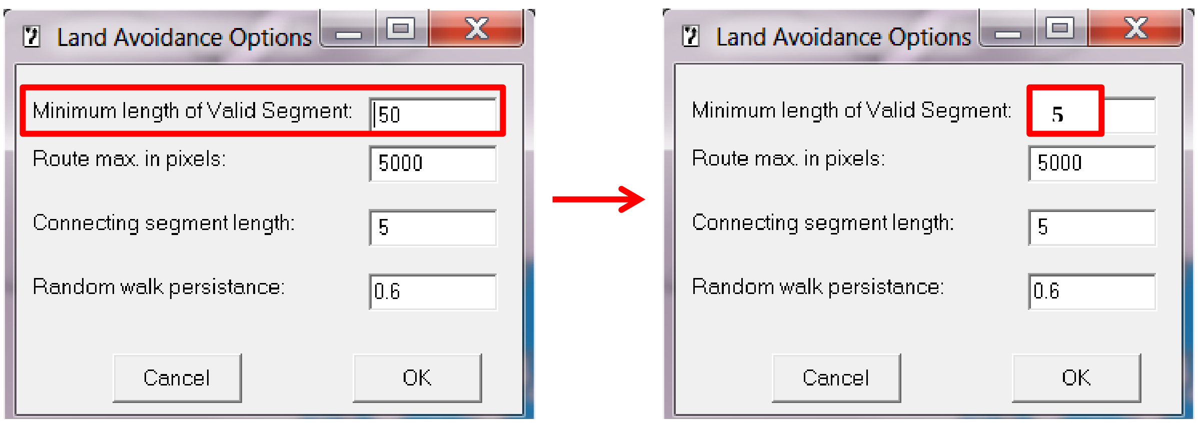



<u>To regain control of the program, simply click anywhere inside the main window, including the status bar or the main menu, then press the **SPACE BAR** once or twice.</u> The program may go on to calculate the next route. You may need to repeat this process if the next route calculation creates another frozen situation. Keep pressing the **SPACE BAR** until the words "Calculating route…" are no longer displayed.

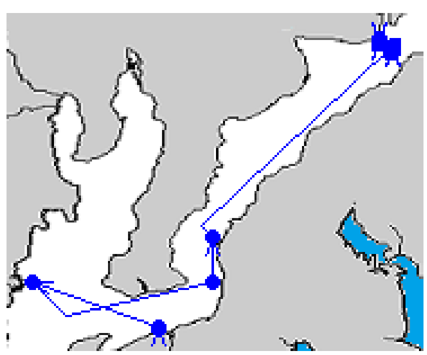
Sometimes **AquaTracker** does not use land-avoidance when you expect it to. For example, below this path does not seem to be using land-avoidance. Why?



The problem is that the ***Minimum length of Valid Segment*** is set too high. The two path segments that go over land in the track above are shorter than 50 pixels. To change this parameter, go to **Options→Change land avoidance parameters**. When we change the parameter to 5 and click on **OK**, the program recalculates the track as shown below.




Now it performs as expected:



To see what effect changing the other paramters may have on your track see Land-avoidance and other miscellaneous parameters.

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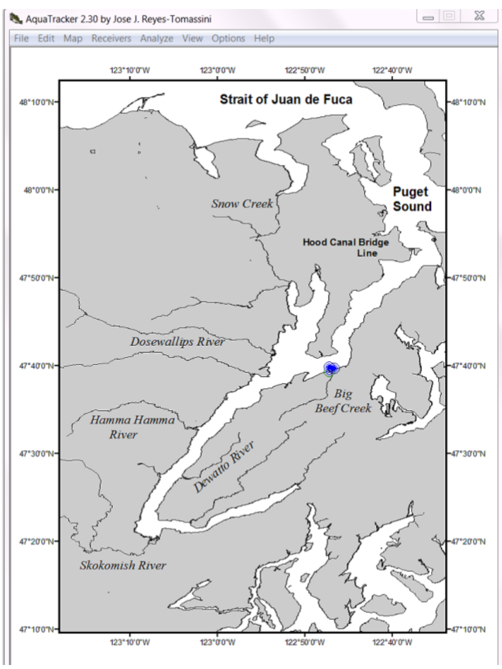
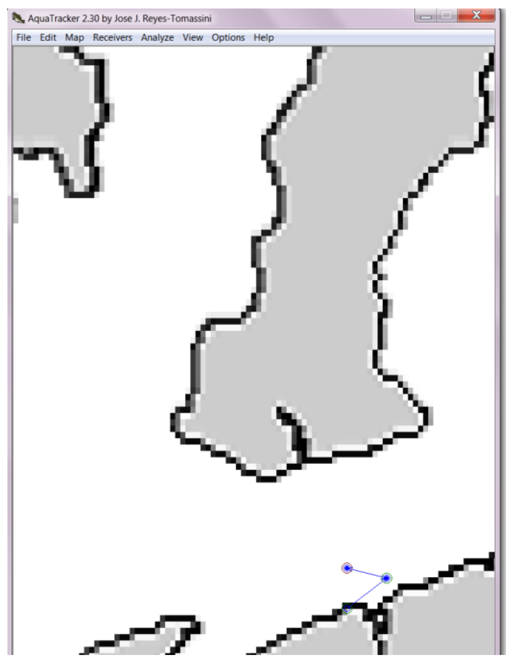
# Chapter 7: Data filtering tools and miscellaneous features

This chapter discusses the features in AquaTracker which allow you to modify the way data is displayed or handled in the program. This chapter also includes a section on modifying track animation and exporting movies. Lastly, you will also find out how to use the measuring tool and the zoom tool.



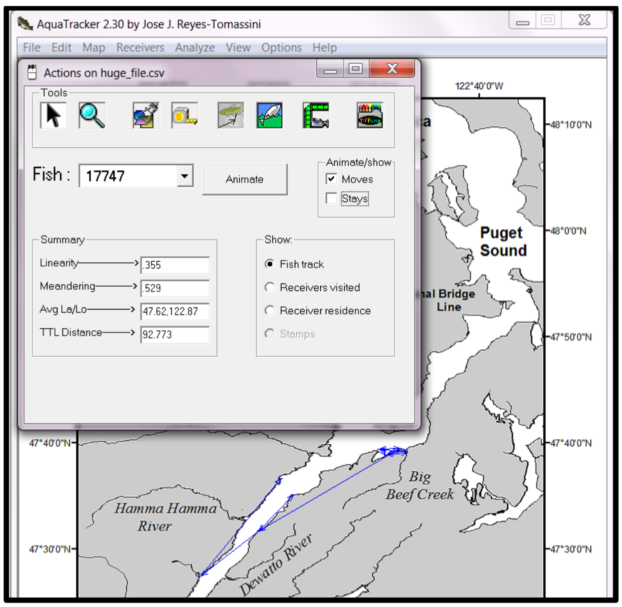



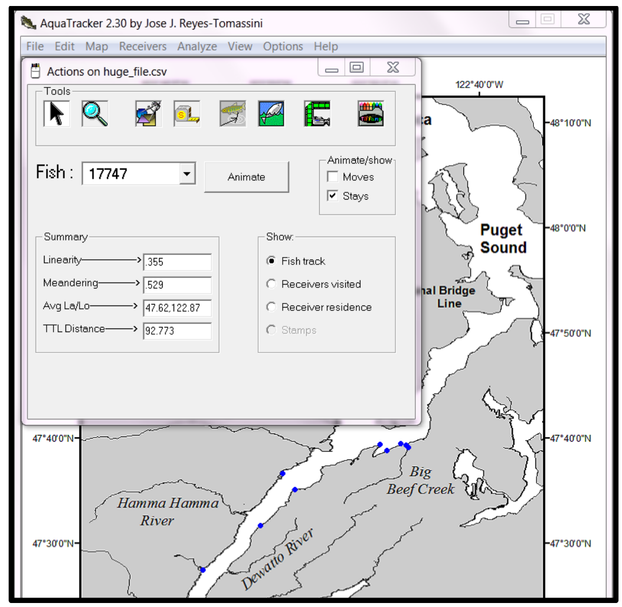

**The effects of the zoom tool in AquaTracker. Here the zoom tool was used during animation. The receivers in this track are very close to each other and the animation is not very clear (Left figure). Zooming allows you to better visualize the track (Right figure).**

## 7.1 Animation options

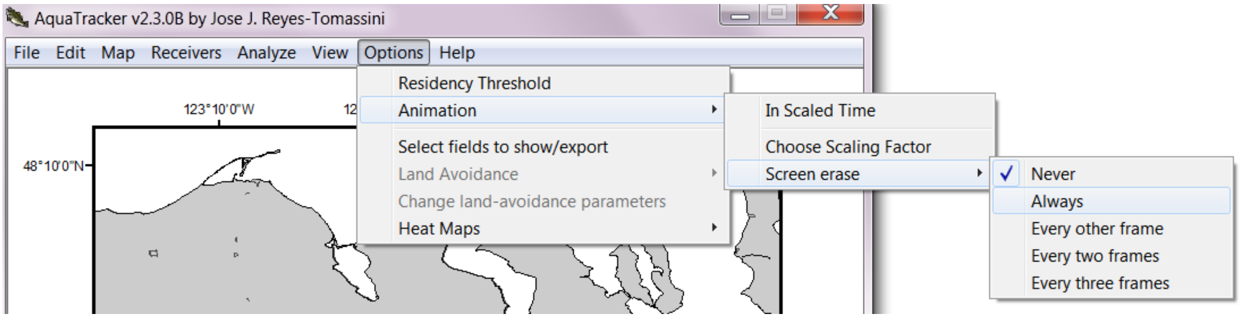
### Selective drawing of stays or moves

**AquaTracker** allows you to animate both *stays* and *moves*. You can select to animate stays only or moves only by going to the **Actions window** and clicking on the corresponding checkbox. The effect of showing moves or stays only is seen below. Note that the radial buttons listed on the **Show** section in the **Actions window** affect the checkboxes (e.g. to selecting to show a fish track forces the moves and stays to be checked).



## Controlling the behavior of animation between animation frames

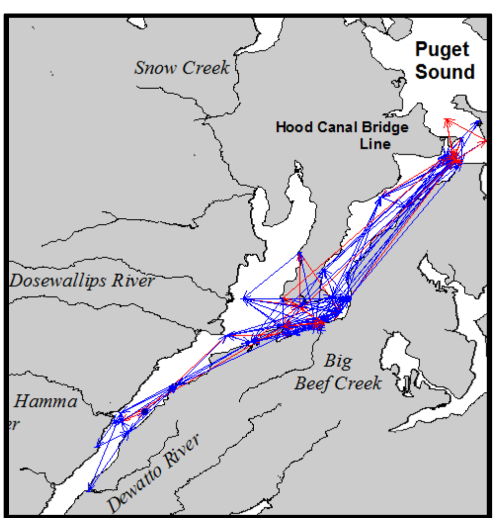



***AquaTracker*** lets you control if and when the canvas is redrawn between fish moves or stays. To see the options available, go to **Options→Animation→Screen erase**. The default setting is *Never* which means that the canvas never gets redrawn and each new track position is displayed after the last without erasing the previous one. Select **Always** if you want only the current track position (a stay or a move) to be displayed on each animation frame. You can also display the next-to-last track or go back as far as 3 track positions, using the remaining options.

## 7.2 Changing a track's color

At times it is necessary to highlight a track or a number of tracks among a group of tracks. To do this, ***AquaTracker*** allows you to change the track color used to draw the track. To use this feature, select the track coloring icon in the **Actions** window  while the track you would like to highlight is selected.

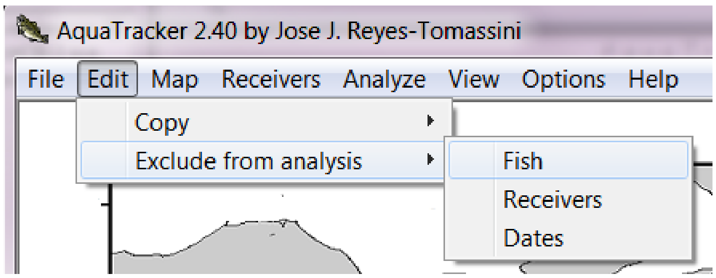
You can also change the track color by using the context menu in the canvas. To do this, right-clicking on the canvas when a track is displayed. Either action will bring the common color selection window.




**NOTE**: *As seen in the figure, tracks can get buried underneath other tracks when displayed together. This is because the program draws each track on the canvas on top of the previous track. To avoid this problem, you can make a track invisible, see section ??*

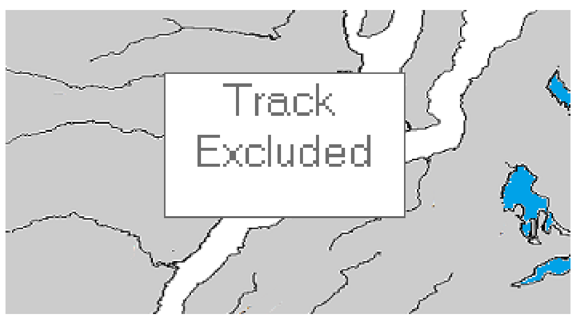
## 7.3 Filtering data by treatment groups or individual fish

You can select which tracks are displayed on the screen when "ALL" is selected in the **Actions** window. To use this feature go to **Edit→Exclude from analysis→Fish**.



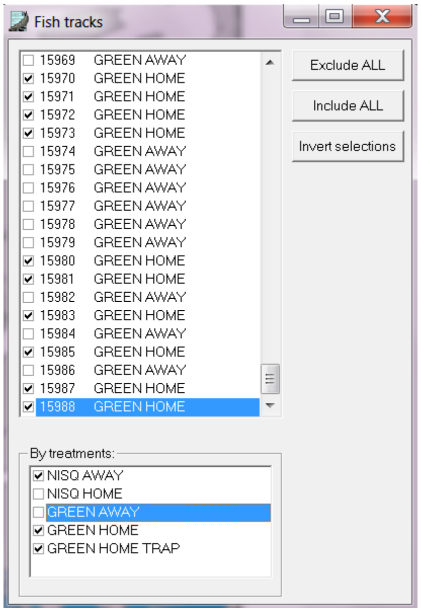

Note, that excluding fish tracks will affect calculations throughtout the program. Thus, **this is effectively a data filtering tool**.

Excluded fish tracks are also no longer visible when selecting them on the **Actions** window. Instead of seeing the plot for the fish track, you will see the following message on the canvas:




Many of the **Action's** window buttons and boxes will become disabled (greyed out). Once an *included* fish is selected, all controls in the **Actions** window will go back to normal and the track for the fish will be displayed in the canvas as expected.

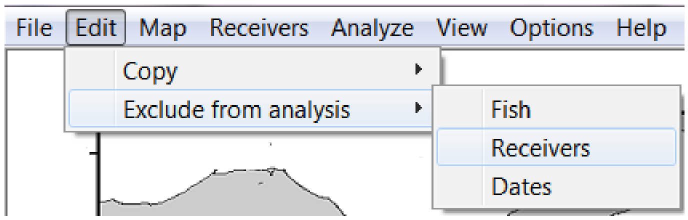
Recall from the section The format of the imported file that ***AquaTracker*** allows you to assign treatment groups during import. You can select which treatment group is analyzed by checking the boxes on the list at the bottom of the window or you can individually select which fish track is excluded or included by using the fish track list on the left.



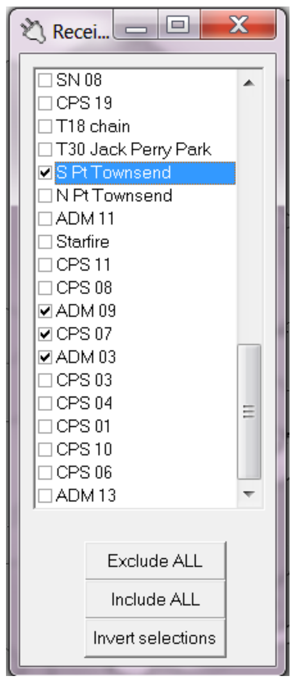

You can also use the **Exclude ALL** or **Include ALL** buttons to exclude or include all fish in the file. By using **Invert selections**, you can alternate which groups get selected and which don't.

## 7.4 Filtering data by receivers

Just as you can do with tracks, you can decide which receivers are used in analyses. This action will also affect which receivers are shown when you go to **Receivers→Show all**. To select which receivers to exclude or include in your analysis, go to **Edit→Exclude from analysis→Receivers**.




**AquaTracker** will show the **Receivers** window, as seen below.



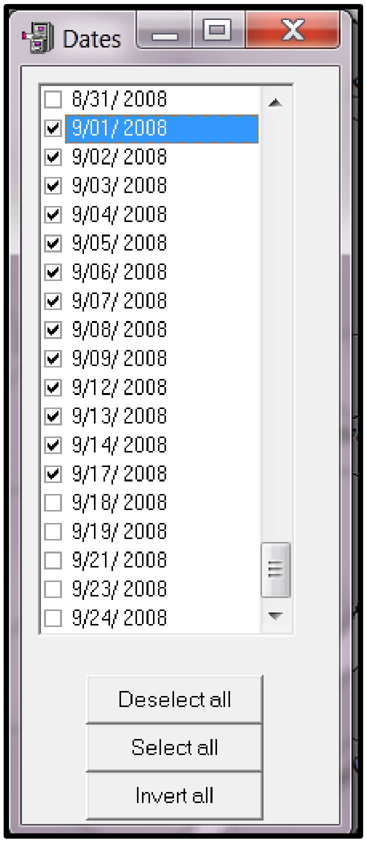

You can choose which receiver to display by clicking on the checkbox in the list corresponding to the receiver's name or you can use one of the three buttons below the list.

> **Exclude ALL** forces all receivers to be excluded from the analysis. This allows you to begin manually selecting which ones you want included.
> **Include ALL** forces all receivers in the file to be included.
> **Invert selections** will exclude any receivers currently included and vice versa. This is useful for alternating between two sets of receivers.

**NOTE**: ***Receiver groups*** *are shown in this window as* ***groups*** *not as individual receivers. Once a receiver is in a group it can't be individually included or excluded unless it is unlinked from the group by deleting the group.*

## 7.5 Filtering data by date

You can filter the data displayed and analyzed in the program by detection date. To make an entire day worth of detection invisible or to only see a specific range of dates, go to **View→Dates**. If the date box is checked in the window, it is included in the analysis. If a date is not checkmarked in the window, ***AquaTracker*** flags the stamps with that date as invalid and they are no longer included in any of the analysis or visualization tools, including animation, tracks, receiver density, etc. Like the previous filtering tool, any change in this window will propagate to any currently displayed analysis or graph. <u>You will only see dates active for the fish or receivers shown in the canvas.</u> Thus, remember that if the **Actions window** is currently displaying ALL fish tracks or the canvas has ALL receivers displayed, then all dates in the experiment will be shown. Any excluded receivers do not contribute dates to this window.

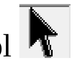


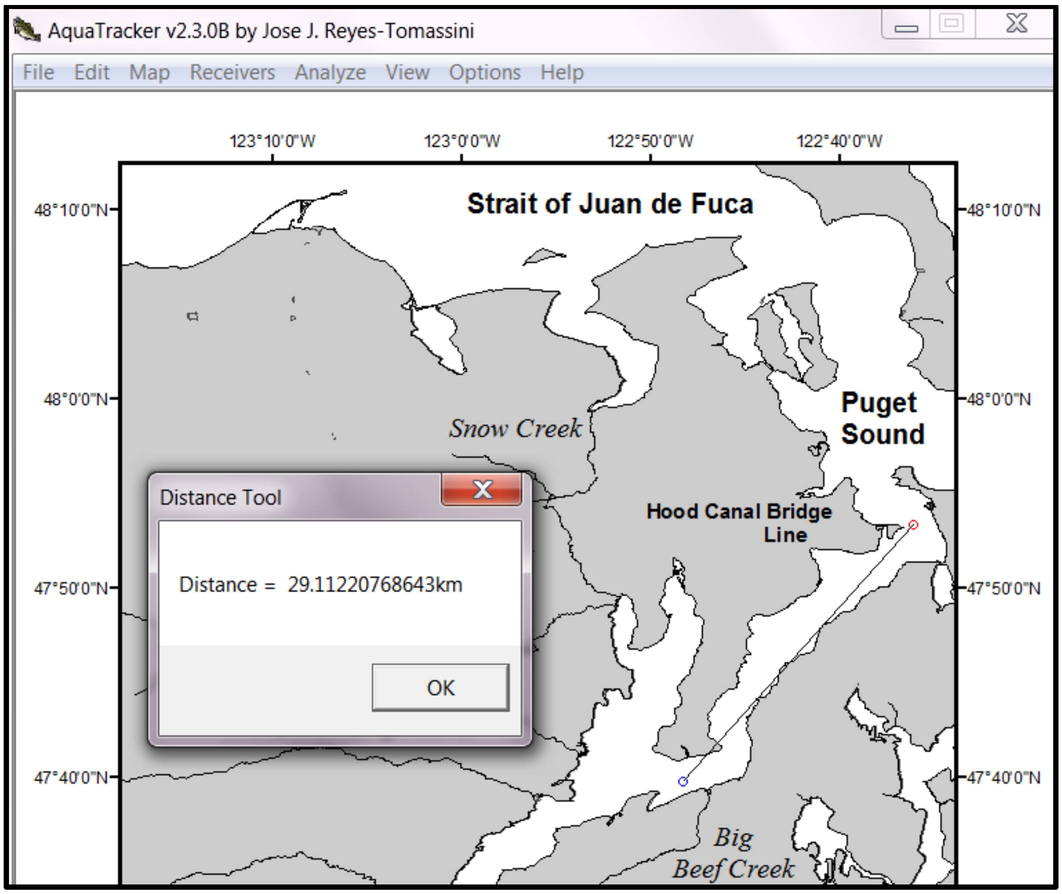

The three buttons at the bottom of the window behave the same as the receiver selection window:

**Deselect all** makes all dates invalid.
**Select all** will make all dates valid.
**Invert all** will make date that is currently checkmarked and valid, invalid and vice versa.

> **NOTE**: *Once you quit the date window, any dates made "invalid" by unchecking them from the list will go back to being valid. This means that when you bring back the window, all dates will be selected again.*

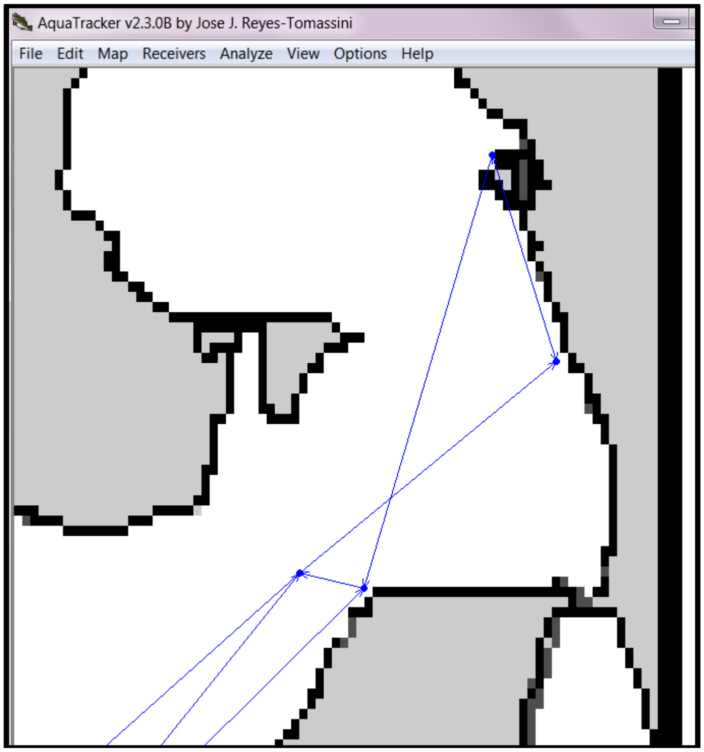
## 7.6 Using the Measuring Tape tool

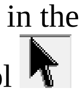
You can use the measuring tape tool  to measure the distance between two points in the map. To use it, select the tool from the **Actions** window and click on the origin point. A mark point should be drawn. Click again on the destination point and the program will draw a second mark point and a line between the two points. A window will pop up to show the distance between the two points, as seen below. Make sure to select the selection tool  again to exit the measuring tool!



## 7.7 Using the Zoom tool

To zoom in on the map, click the Zoom  tool on the **Actions** window. The map on the canvas will be enlarged by XXX%. Receivers and tracks are redrawn by calculating their new relative location on the zoomed map, effectively allowing you to zoom-in on the map.



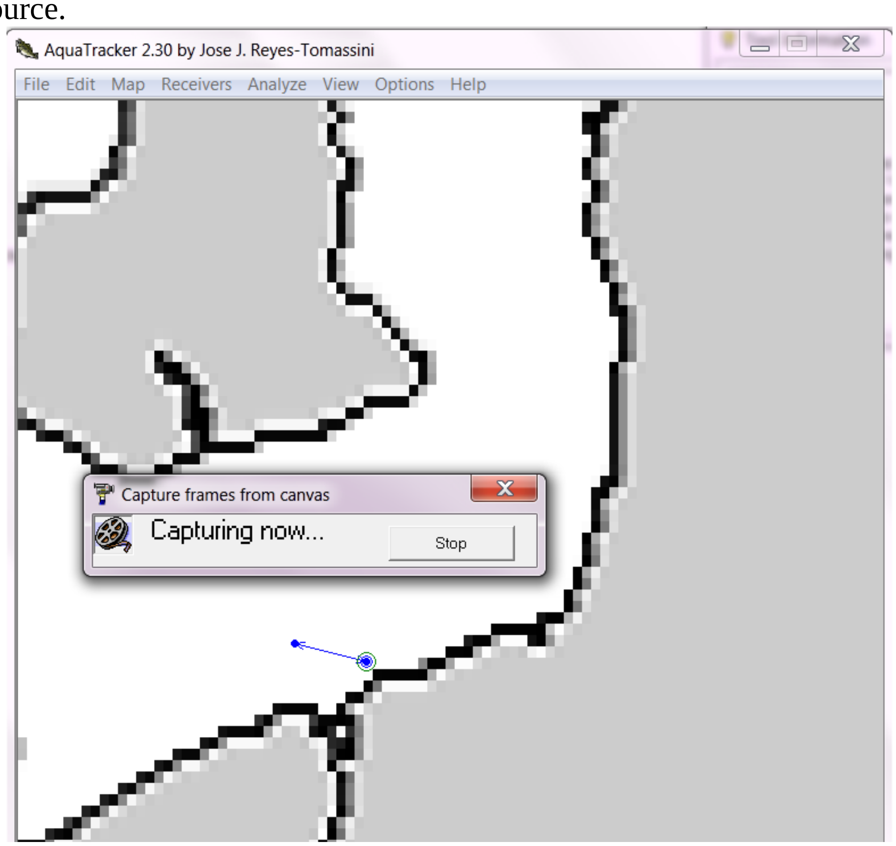

To exit the zoom feature, simply click on any area in the canvas and the program should show the whole map again. Go back to the selection tool  so that you do not zoom in on the map again.

## 7.5 Exporting animations to AVI files

Animations can be exported as movies to be used in power point presentations. You can capture any animation that is displayed in the canvas (i.e. tracks, receivers residence, stays/moves, etc.). Once capture begins, the program will save an image of the canvas 4 times a second. To begin capture, click on the Capture icon  in the **Actions** window. The program will then ask if you want to use the default (or last) filename to save the file. Answering yes to this question will overwrite the last animation movie file.

After you indicate where the AVI file is to be saved, the program will begin capturing. The **Capture** window will be shown, as seen below. Now you most start the animation in the program by choosing the track to animate and clicking on the animate button. Anything drawn on the canvas will be recorded until you click **Stop**.

If **AquaTracker** can't find a proper codec for compressing the true-color (24-bit) image in its canvas, it may warn you that no codec was found and you won't be able to create an AVI file. If you are using a computer at an office, contact your IT department and ask if they can help you install a codec pack. If you are using your personal computer, search for a codec pack with a 24-bit AVI compressor and install it. As usual, be careful of what you download from the internet. Codec packs are known to be malaware vectors. Only download codec packs from a verified and trusted source.



# How to credit the author of the program when you use AquaTracker in the analysis or visualization of your published work

*AquaTracker* is a public domain computer program. It is offered as-is, without any warranties expressed or implied. The author only asks that proper credit be given if the program is used in the analysis or visualization of published data. Credits should include the following information: José J. Reyes-Tomassini and the NOAA Pacific Northwest Fisheries Science Center.

The following reference should be used in any peer-reviewed manuscript or published work:

Reyes-Tomassini, J., Moore M., and Berejikian B. AquaTracker: A data exploration software for acoustic telemetry. *In Review, submitted to Methods in Ecology and Evolution (??)*

Also, after the article is accepted for publication, email Jose.ReyesTomassini@noaa.gov with the publication title and name of the journal where it was published. This information will help support further development of *AquaTracker*.

# Appendix A: Data Model

**AquaTracker** considers a detection to be a ***stamp***. A stamp is package of information which contains the following:

1) ID of Receiver
2) ID of Fish
3) Time and day of detection
4) An internal representation of time, called CTime, which is analogous to the astronomical Julian Day, with a different base time.
5) Valid (flag), set to TRUE by default. Singleton deletions or Excluded dates will have this set to FALSE.

Stamps are sorted and placed in a Receiver data container/table. For each receiver in this table, stamps are sorted chronologically. Similarly, a "Fish" container is created, and for each fish entry in this container, the stamps are sorted chronologically. This is how fish tracks are created!

Each of these two containers has a table associated with its data.

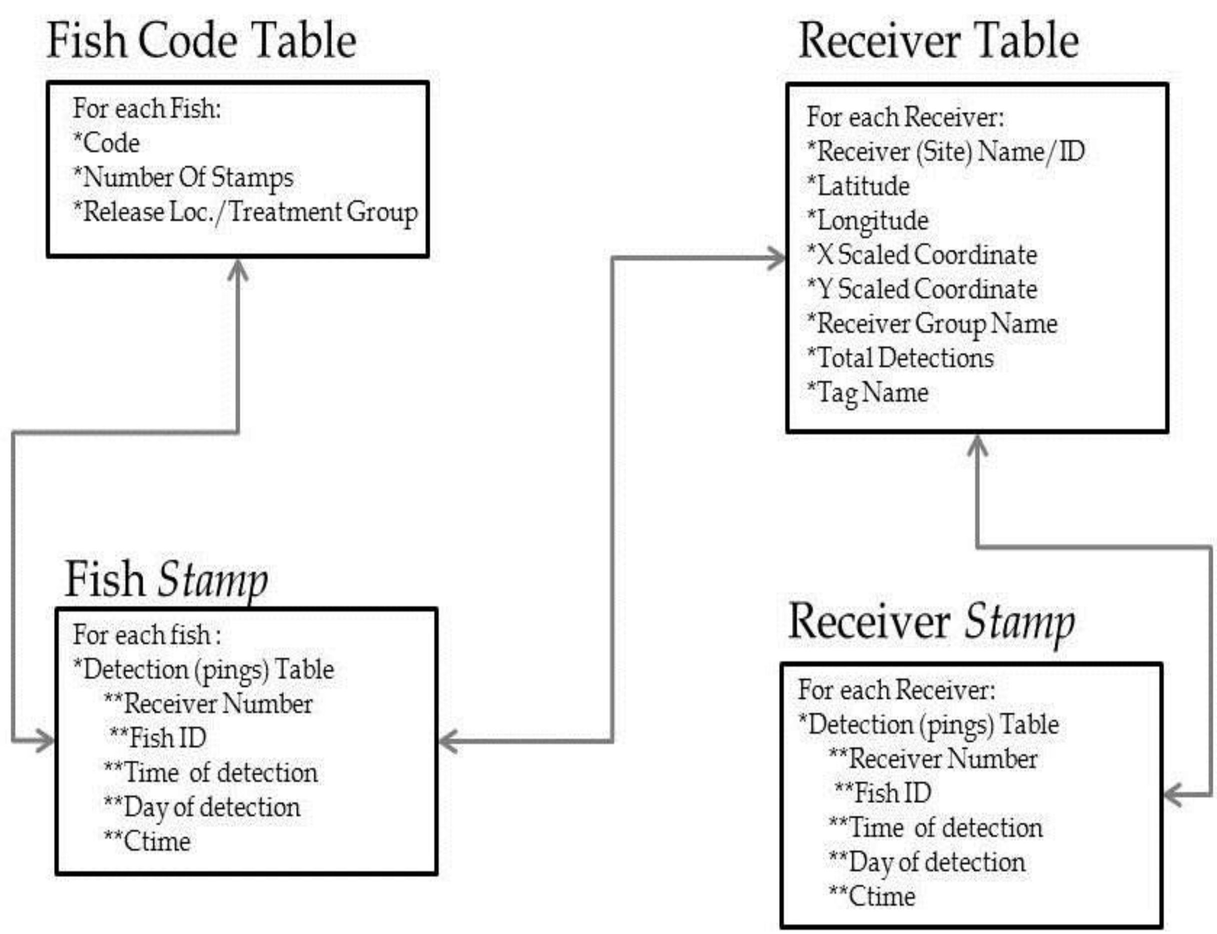
1) **Receiver Table**, for each entry:
    a. Name of Receiver (ID)
    b. Lat/Long of Receiver
    c. X/Y scaled coordinates of Receiver
    d. Receiver Group Name if grouped
    e. Total detections (used to query the receiver stamp container)
    f. Excluded flag

2) **Fish Table**, for each entry:
    a. Fish ID
    b. Release Location/Treatment Group of fish
    c. Total detections (used to query the fish stamp container)
    d. Excluded flag

There is also a **Route table** which stores the waypoints and total oceanographic distance for track segments between two receivers. A **Group Table** also exists that contains the information about receiver groups, including the representative receiver id. AQN files save the stamps in the two containers in sorted order and the information on these four tables. This is one of the reasons that AQN files are at least twice the size of an unformatted CSV file.

# AquaTracker's Entity Relationship Diagram

## *Fixed Receivers*



# Appendix B: Program Limits

### Parameters related to detections

| Parameter | Limit | Description |
|---|---|---|
| Entries per file* | 8,388,608 | Total detections in a file |
| Detections per receiver | 2,097,152 | Total detections per receiver |
| Detecions per fish | 2,097,152 | Total detections per fish |
| Number of fish | 500 | Total number of fish in a file |
| Receivers | 255 | Total number of receivers in a file |

### Parameters related to grouping and analysis of receivers

| Parameter | Limit | Description |
|---|---|---|
| Overlapping pairs | 2,000 | Limit used in overlap analysis. Maximum number of overlapping pair of receivers. |
| Receivers per group | 75 | Maximum number of receivers in a group |
| Groups | 50 | Maximum number of groups that can be defined by user or auto-grouping |
| Zones & Ecological tags | 50 | Maximum total number of defined zones or ecological tags (combined) that can be created to assign to receivers |
| Days in Plot | 3650 | Maximum number of days that can be plotted by Detection Scatter Plot (10 years worth of data). |

### Parameters related to fish and track analysis

| Parameter | Limit | Description |
|---|---|---|
| Excursions per receiver or per fish | 5,000 | Number of times a fish can go out of the receiver range and back. Excursion defined by a threshold time that fish has to be outside detection of receiver. This is used by receiver excursion analysis. |
| Fish groups | 500 | Number of fish “schools” (fish group analysis tool) |
| Track string length | 30,000 | Number of characters that make up a track string. Anything beyond this will be truncated and not reported on-screen or on-file. |

## Land-avoidance and other miscellaneous parameters

| Parameter | Limit | Description |
|---|---|---|
| Map/canvas size | 1024 by 1024 (pixels) | This is the size in pixels of the map or canvas. |
| Contour size | 4,000 (pixels) | Size of the contour traced (see next Appendix) |
| Max distance to corridor | 2,048 (pixels) | Distance from a corridor to a receiver. If distance is larger than this, receiver won't be connected to corridor. |
| Anchor points | 100 | Total number of anchor points used to create fish corridors. Each time you click on the mouse, an anchor is deployed. |
| Routes** | 2,550 | Total number of routes that can be stored by the program. |

**Special Notes:**

**I have not loaded more than 200,000 detections but the program only takes 10 seconds to load that many detections. If you try to load, say one million detections, you may have to wait a minute or two before the program becomes responsive between tasks. I think anything more than 500,000 detections could be impractical. E-mail me if you have a data-set that contains half a million or more detections. There are ways I can improve the program and if this becomes a sticking point for users, I can probably get it to work. I see very few instances where a user will have anything more than a couple of thousands of detections and even then, it is possible to filter out detections from dead fish, fish that are in the belly of marine mammals, etc. so that the main AquaTracker detection data file can be made smaller. The overlap analysis tool within AquaTracker can help screen out detections from marine mammals that have consumed a fish. The residence analysis tool can be used to find dead fish near a receiver.*

***An array can have up to 255 receivers but may only have up to 50 receivers connected to each other to form tracks ($50^2$ = 2,500 routes). This should provide plenty of room for large arrays because not every receiver will have tracks connnecting it to every other receiver in the array. In fact, fish tracks usually follow a specific path. Also, receivers that are not connected by the hydrology or oceanography of the region will not join to form a track.*

# Appendix C: Shoreline-based land-avoidance

## The algorithm

**AquaTracker** uses image analysis techniques to extract relevant futures from the map. The two main futures extracted from the map are the location of water and the location of land/water boundaries. The information generated from reading the map is by land avoidance algorithms to successfully navigate the map.

To find the boundaries or edges between land and water, the program uses "edge-finding" and "edge-thinning", image analysis techniques which convert the image into an edge-image (This edge-image is shown when the program displays the map under the Receiver Information Window).

By default, the program assumes that white pixels represent water and that anything that is not water is land. You can choose a different color to represent the water see 1.5 Selecting water pixels (for maps with water as non-white pixels).

The program checks if the line it draws between each pair of receivers in a track is over water. If the program finds that a line runs over land (default: >50 pixels), it will attempt to "re-direct" the line by routing it over water instead[1]. The re-direction of a line that goes over land is accomplished by finding the exact entry-point into land as well as the exit-point (and water re-entry). The algorithm uses these two points as the target points for its contour-following. Contour-following is a technique used in image-analysis to find the pixels that make up the perimeter or edge pixels of an object. Since the entry and exit points both lie on the edge-image of the map (they are, by definition, edge points), following the contour from target point to target point yields the edge segment that connects the two points. The distance between this two points running along the edge is the coastal distance.

The contour-following algorithm is set to accept no gaps[2]. Thus, there can't be any holes in the map contour. By default the algorithm has a 600 pixel limit as to how far it will "stray" from the target[3]. Note that this limit could be exceeded if an island or peninsula is big relative to the total size of the map, and the exit and entry point are at opposites end of it or there is a lot of shoreline between the points. Whenever following a contour if the algorithm arrives at a branching point (e.g. the shore goes inland or continues, as in near a river delta), the search direction is chosen randomly. After a contour is found, the algorithm iterates (repeats the process) 5 times and choses the shortest route that results out of the 5 times it attempted to trace the route[4]. It is assumed that if one or more branch points exist, then each iteration will yield a slightly different result as the algorithm will randomly choose a different branch to follow each of the 5 times.

The maximum allowed total coastal or shore distance between land-entry and land-exit is 4,000 pixels[5].

The pixels that make up the shortest segment of the contour are passed to another algorithm. The algorithm then picks an edge (shore) pixel, from every 10 pixels in the contour, as a vertex in the path segment it creates[6].

The important variables are summarized below. Almost all of them are user-programmable, but changing them is only suggested if you are willing to allow the program to hang, quit, or crash. This table may also help you assess the possible artifacts introduced when you manipulate your map image or it might help you troubleshoot problems related to the quality and source of your map.

**Table of Programmable and Constant Parameters for the Shore-based Land-Avoidance**

| Parameter | Units | Description | Default Value |
|---|---|---|---|
| *Minimum length of valid segment*[1] | Pixels | Threshold above which a segment is considered over land. | 50 |
| *Loop Length*[4] | Times | Total times algorithm calculates a distance. Lowest value chosen. (*Not under user control*). | 5 |
| *Gap*[2] | Pixels | (Not under user control. Algorithm assumes no gaps.) | 0 |
| *Max. coastal distance*[5] | Pixels | Maximum distance between connecting points along coast or shoreline. (*Not under user control*) | 4,000 |
| *Max. deviation from route*[3] | Pixels | Maximum Pythagorean distance algorithm “strays” from route. | 600 |
| *Connect segment Length*[6] | Pixels | Size of each of the segments created by the algorithm which connect the two land entry points. | 10 |

# Fixing Problems with the map

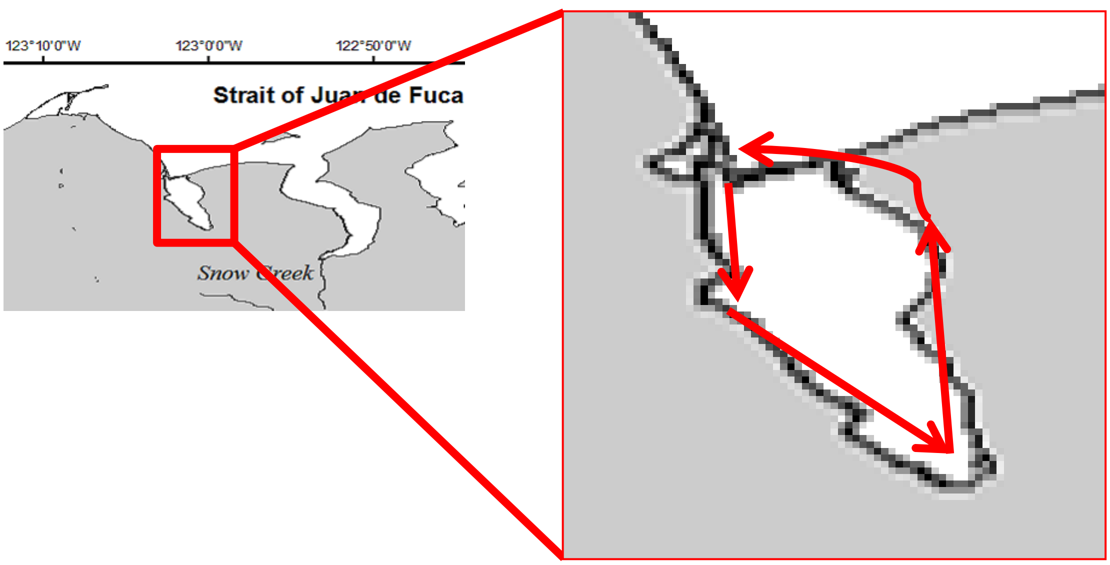
The map image itself is at the heart of the land-avoidance algorithms. This is especially true for the shoreline-based land-avoidance. The algorithm can halt or crash if the map contains certain spurious artifacts. In general there are three types of failures for the land-avoidance algorithm when using the shoreline: **distance threshold**, **circular routes**, and **path divergence**. Sometimes these failures are interrelated, e.g. path divergence will almost always end up causing the distance threshold to be exceeded.

## Distance Threshold

If the distance between the land-entry point and the land-exit point for the line that goes from the origin receiver to the target receiver exceeds the threshold number of pixels, the algorithm will stop. To fix this problem, choose a higher threshold or choose a different map with a smaller displayed area.

## Circular Routes

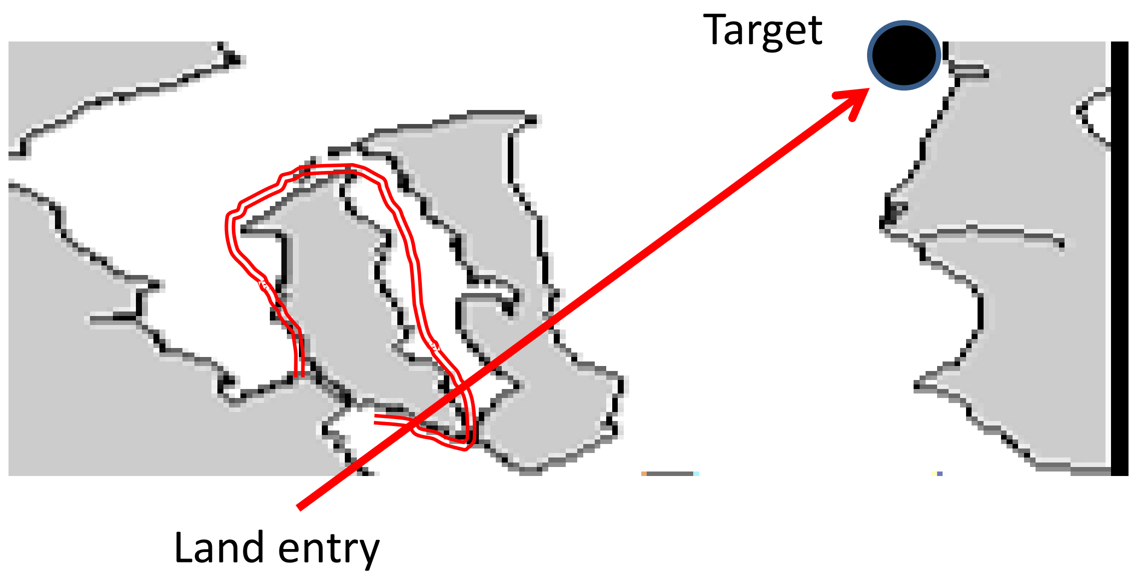
When the algorithm is following the shoreline, it may encounter real or spurious features along the shore which loop back. As seen below, this is a common issue with bays that have sand spits or bridges which do not connect the feature all the way. You may want to simply use a graphic editor to fill the feature or block it all together. This can be accomplished by erasing the spit/bridge or filling the feature using the land color.



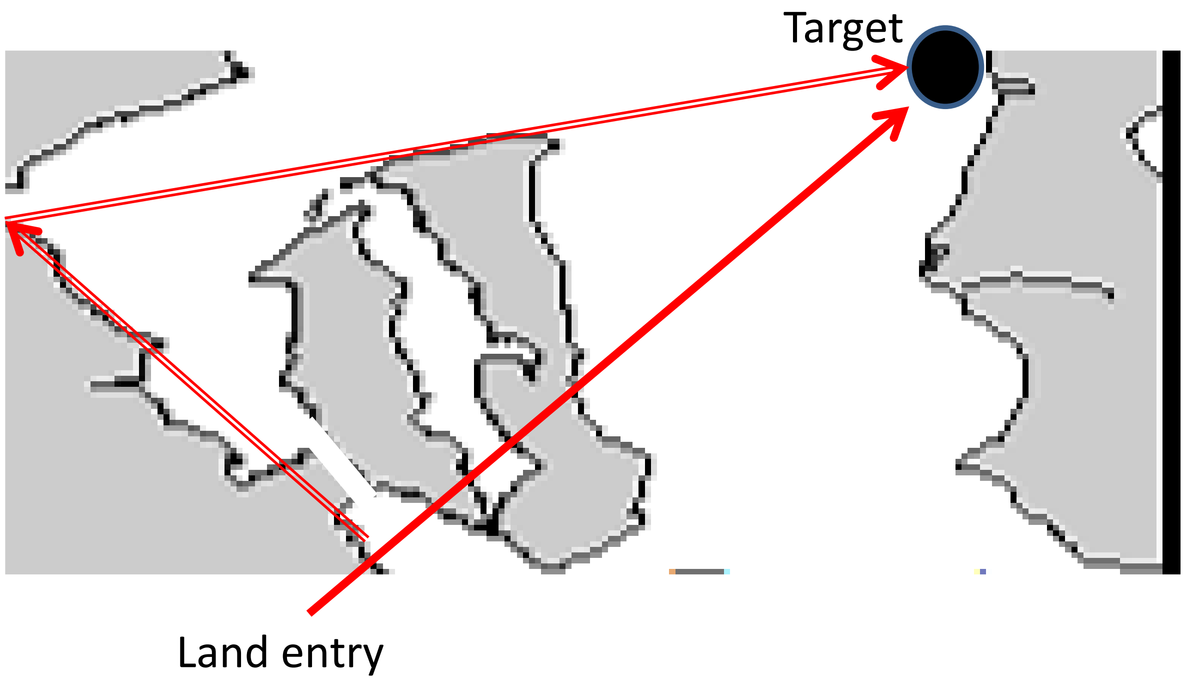
## Path Divergence and Islands

Path divergence can happen around features that are too close in geographical distance. Another cause of path divergence is the presence of large bays or islands in the route of the path. I have only encountered one instance of path divergence that lead to failure of the algorithm. This was due to an island which in the map was so close to the main land that the shoreline-following "jumped" from the main land to the island then did a **circular path** around the island, backed down on the path, which halted the search (because the computer thinks the shoreline has ended). To solve this problem I removed the connecting pixels from the map.

The example below illustrates a hypothetical failure, similar to what I have observed in real life (I can't remember now which map and data created the problem!). The presence of a larger island serves to occlude the target, as the algorithm can't find any route that goes through water. In reality, the algorithm will usually break this into two sections so it may actually not fail, but the example serves to illustrate the key concepts of path divergence and how to handle islands.



To force the path to go thru water, and so that it does not break into two path segments (around the first island, then the second), here is a possible solution:




The part of the land mass that connected the two islands to the main land area was removed. Here, I have exaggerated the amount of land removed to illustrate the point but you only need to remove a small number of pixels to obtain the same result. Note that the new path is perhaps more direct but may not reflect the path the fish took. A possible future solution (which I have considered) is to take the time between receivers to decide which route the fish took. Also one may also consider the topography of the array (i.e. did this path took the fish around a possible receiver that did not detect any fish?), etc. to build a path that is a much better <u>guess</u>.

# Appendix D: Common Import Problems and Error Messages.

The following is a list of common import problems and/or error messages with possible causes and fixes. NOTE: Most errors encountered and reported by users of previous versions of **AquaTracker** occurred during import. <u>More than 75% of these were caused by incorrect import file format, including missing columns, columns with zero/blank values, columns with invalid lat/long coordinates, and users importing files that exceeded the limits of the program</u> (See **Appendix B: Program Limits**). Also, note that a CSV file can't have any commas in any of the fields. Thus, <u>fish codes and receiver names can't have any commas</u>. Finally, make sure that the file follows strict CSV formatting: it should not use any other "separator" and each row should end with a carriage return (you can use ***Notepad*** to verify the file is in the right format by comparing it to the sample files provided).

| Problem / Error Message | Possible Cause | Fix |
|---|---|---|
| ***Error at XXX: Incorrect Day Format*** | Day String is not correct. Sometimes this is due to an incorrect time stamp with a value of 0. | Check row # XXX. This is the row (0-based) where AquaTracker encountered the error. |
| ***Incorrect File Format: Import Error.*** | When using the older, non-tagged, file format, this error can occur if one or more columns are missing. | Check import file for missing column or incorrect column order (when using non-tagged columns). |
| ***Warning: Loaded with XXX bad long/lats AND/OR XXX unconforming data points.*** | A zero-value Lat. Or Long. was found in the LONG or LAT column OR blank fish code was found on a FISH CODE column. | Search your import file's lat and long for the "bad" (zero-value) coordinates OR search your import's file for an "unconforming" (blank) fish code. |
| ***Run-Time Error 9*** | If during import, this may happen because of an incorrectly formatted date. | Check the file's time column for an incorrect date/time stamp. |
| ***Run-time Error 53*** | If seen during import, this is most likely caused by an invalid file path. | Try using a different file or copy the file to a different folder. |

# Glossary

**1st Order Markov Chain**: In **AquaTracker**, a Markov chain is formed as follows. If every time a fish visited receiver B, it goes to A after visiting B, then this two receivers are linked by a Markov-chain of the 1st order. Note that Markov chains can have a forward probability different than its reverse probability. For more information, see the text.

**%RA Active:** Percent of the total receivers that are active in the selected fish track. This is analogous to the coverage area and might be a measure of habitat usage depending on your specific experimental design. It assumes that overlapping receivers have been grouped. It is calculated as Receivers in Track divided by Total Receivers in Data Set.

**Auto-Scale:** It is the process of finding a scale that adjusts to the coordinates provided by the imported data file so that all the plots points are displayed in the screen. The software automatically selects the right-most and bottom-most, and left-most and upper-most, coordinates so that they are located within the boundaries of the canvas.

**Control Points:** In a geo-referenced map, control points are locations in the map for which the Lat/Long coordinates are known. Two control points are needed to establish the map scale.

**Density of Detection:** In **AquaTracker** detection density refers to the relative number of detections by a receiver on a specific date or a range of dates. Density is shown by taking the number of pings heard by the receiver and dividing it by a fixed factor. The results are graphically displayed by showing the relative density as a function of the color of each receiver plotted. Thus, the higher the density, the more "color" (if using the grey scale, receivers with more detections are shown as darker receivers), although the exact color used to draw a bin can be changed.

**Detection scatter plot:** A plot made up of all the detections in the file identifying where the fish was on each day or where most of the detections occurred each day for each fish (up to two receivers per day). The plot shows each individual fish on the Y-axis and each day in the dataset is shown on the X-axis. It is a way to visualize the entire detections into one graph. It can show the movement of fish towards some specific area of the array when combined with the *distance-based heat map* or when using color to identify receiver or receiver groups in the plot. If a fish was detected on three receivers or more during a 24hr period, the two receivers where the fish spent most of the time are used in plotting the point.

**Distance-based heat map:** A representation of the distance from each receiver to a specified (aka Origin) receiver in the map. The specified receiver is chosen by the user using the **Receiver Information window**'s Change Marker option. The distance between the receiver and the origin receiver is converted into a color scale. Grey-scale is the only option available for representing the distance. The darker colors represent receivers farther from the origin receiver. Coloring receivers this way allows for using the distance-based heat map with the detection scatter plot to effectively visualize and consolidate the entire detection spread into one figure.

**Excursion:** An excursion is the movement of fish from outside of the range of the receiver (or group of receivers) and back. It is the inverse of residence time. It is analyzed by **AquaTracker** using the Show Excursion option of the Receiver Context Menu. Excursion time is given in minutes.

**Fish ID:** The code used to identify the acoustic tag. Generally speaking, it's a numeric code. The program accepts only decimal codes or hexadecimal codes (which are converted to decimals). The fish ID serves to organize the stamp information into tracks.

**Geographic tags**: Tags defined by using the select tool and drawing a rectangle around the desired area. The defined zone is saved as part of the receiver information file.

**Geo-referenced map:** A map in which each pixel can be correlated to a known Lat/Long coordinate.

**Minkowski distance (*p*):** The Minkowski distance of order $p$ is a measure of the difference between two values (distance) in a normed vector space. One way to visualize what this means is to think of a taxi trying to go from point A to point B in a city. The taxi can only use the streets, which are on a grid. If the taxi uses the streets ($p = 1$, moving in one dimension), the distance is much greater than if he was allowed to travel directly there ($p = 2$, moving in two dimensions in one move). Thus, decreasing the value of $p$ makes the distance calculated much bigger for that specific value, increasing the cluster separation on that parameter. **AquaTracker** does not allow values of $p$ below 1, because this generate non-metric spaces that are useless for clustering.

**MJD or Modified Julian Date**: The internal date representation of the program is a special version of the Julian date. The MJD is the total number of days since the base "epoch", which is chosen arbitrarily. To consolidate both date and time, the program multiplies the MJD by 1440 minutes in a day and adds the time (as number of minutes past midnight) to obtain a single number that represents both date and time of detection.

**Move**: A move occurs when a fish is consecutively detected in two different receivers. Receivers with overlapping radii can cause stays to be mistaken as moves. This is because anytime a move occurs the distance traveled is recalculated and updated. Thus, overlaps will create incorrect distance calculations.

**Overlaps**: Overlaps are detections that occur almost simultaneously in two different receivers. They occur when the detection radii of two or more receivers overlap. When receivers are setup so that they act as gates or lines, overlaps are expected. However, sometimes tidal currents, biological factors, and other unpredictable events, can affect the detection radius and create overlaps where none are expected. **AquaTracker** can detect these overlaps and can automatically group overlapping receivers to avoid mistaking these overlap detections as moves.

**Pings:** **AquaTracker** uses the word ping to refer to the acoustic signal heard by the receiver, and also to the **stamp** that it creates when the receiver logs the information to its memory. See also ***stamp***.

**PSI La**: Path Similarity Index Latitude. This is the average latitude of all detections in a given path. Theoretically, it can act as a similarity index because the more similar path will have very similar PSI. You can also see this number as the centroid of a track.

**PSI Lo**: Path Similarity Index Longitude. See **PSI La**.

**Range:** The travel range is the distance between the farthest two points along the travel path. It is needed to calculate **tortuosity** but it might be a useful measure of habitat usage and exploratory behavior. For an example of how to calculate range, say a fish travels back and forth four times between two stations located 1 km apart, he will have traveled 4 * 2 * 1 = 8km (if ending on the station it started). The fish will have a net displacement of zero, a range of 1km and a total distance traveled of 8km. Range is given in kilometers.

**Ranging Index:** If migration is the large-scale movement of animals, then ranging is medium-scale movement. **AquaTracker** calculates a ranging index based on the number of receivers visited divided by the total number of "transitions" to different receivers. For example, two fish visits receivers A, B, C, and D. Fish #1, visits A, B, C, D and then he goes back to A, then D, and finally he is detected at B before the end of the experiment. During the same period Fish #2 visits A, B, C, D in that order. The ranging index for Fish #1 is 3/5, while for fish #2 it would be 3/3. The closer the index is to 1, the more "ranging" behavior is being observed. The smaller the ranging index, the higher the tendency of the fish to stay within a "known" area. This index only works in certain receiver deployment setups and it only works if overlapping receivers are grouped. The index is a ratio and is not scalar.

**Receiver group:** Two or more receivers can be grouped by the user or by the overlap analysis tool. When receivers are grouped, the stamps belonging to each individual receiver are consolidated into the group. The receivers used to create the group will be set to *excluded* and you won't see them anymore as individual receivers. Instead, a *representative receiver* will be "deployed" at the average coordinates of the group. This receiver will be available for analysis and visualization, just as any regular receiver in the dataset. AQN files save all the information from receivers in a group, including the representative receiver for the group.

**Reference track:** A track used as a reference for a cluster-type analysis. The program looks for tracks similar to the reference track in the dataset. The reference track can be a track from a fish in the dataset or a track created by the user using the **draw reference track** tool. By default, reference track clustering is heavily biased towards position (latitude and longitude). Position is thus the main parameter used to decide if two tracks are similar. The influence of track average position on the reference track analysis can be changed in the **reference track** window.

**Release Site:** The Release site is used as a field to assign the fish to an experimental or control group. It can contain any string. It is not used in any of the analytical calculations.

**Representative receiver:** When receivers are grouped, **AquaTracker** creates a representative receiver for the group. The representative receiver is assigned a number, just as the other receivers, and drawn in the map. The user can access the receiver group's stamps by way of the representative receiver. The program treats this receiver as any other in the dataset.

**Re-Plot:** A re-plot of the data has to be performed because the program automatically assigns X and Y plot coordinates as soon as it loads your data into memory. A re-plot just means that given the new scale and origins, the program will re-calculate those X and Y coordinates for your data.

**Residence time:** The cumulative amount of continuous time spent by a fish around a receiver. Certain criteria regarding the time between detections must be met, which are explained elsewhere in the manual.

**Singletons**: A singleton is a single detection occurring in a set time, usually a 24 hour period. Some researchers discard singletons and view them as acoustic noise or incomplete detections.

**Stamps**: A stamp is the basic detection "unit" in **AquaTracker**. A stamp contains the fish code, receiver where detection occurred, and the time and date of detection. It is used internally to represent the data.

**Stay hours**: Number of hours at **stay site**.

**Stay Site:** Name of the receiver where the fish spent the longest time (as measured by the time elapsed between pins at the same receiver).

**Tags**: A tag is a label that can be given to any receiver or groups of receivers. Tags should be used for niche and habitat usage analysis. **AquaTracker** can calculate what percent of the total receivers visited by a fish belong to a specific tag. Tags can be **geographical** (defined by geographic zone) or manual (defined by user).

**Track string:** A track string is a verbose description of the track based on the receiver names or receiver identifiers. Track strings can quickly convey information of where the fish traveled in the array. A track string can be very long. To shorten track strings, **AquaTracker** uses bidirectional arrows to indicate movement back and forth between pairs of receivers. You can also shorten track strings by grouping overlapping receivers.

**Linearity:** As calculated by **AquaTracker**, the linearity of a fish track is the range divided by the total distance. If the travel path is tortuous, linearity is low. If the animal travels in a direct line, linearity is close to 1. Linearity and **ranging** are related.

**Total Distance Traveled**: Total cumulative distance traveled. This includes all the moves between stations regardless of where the stations are located in relation to each other. For example, if a fish travels back and forth four times between two stations located 1 km apart, he will have traveled 4 * 2 * 1 = 8km (if ending on the station it started). The fish will have a net displacement of zero, a range of 1km and a total distance traveled of 8km. Total distance traveled is measured in Kilometers.

**Total Time**: Total time is the cumulative total time of travel. It is NOT the difference between the time of first detection and last time of detection, but the cumulative difference of all the times elapsed between detections. Total time is measured in days.

**Travel Rate:** The travel rate is calculated by **AquaTracker** based on the total distance traveled divided by the difference between the first time of detection and the last time of detection. It is not an averaging of the instant speed (i.e. travel speed between two contiguous detection points) but the cumulative distance divided by total time. This is done to avoid calculation errors introduced by the uncertainty of the detection radius of each receiver and to account for the fact that between detections, the position of the fish is not known. Given as meter/hour.

# Source code availability and program extensibility

**AquaTracker** is public domain software. If anyone wishes to pour over the code in order to find possible bugs or create new tools, I would gladly email you the entire source code, which is now more than 12,000 lines of code. The program is written in Visual Basic 6.0 and is modeled using Object Oriented Programming standards (where I could, I admit, at times I went old-school and did some pretty awful coding due to time-constraints!).

Adding more tools to **AquaTracker** is easy once you understand the way data is handled. Because it is object oriented, it is pretty easy to do simple analysis and visualization. To draw a line between two receivers, you use the **Receiver** object and its **DrawRoute** method (if land avoidance is selected, this will draw the land-avoidance track too!).

To obtain information about a fish track and draw all the points in the route, you would write code like this:

```
Private Draw_Receiver_Within_Fish_Track_As_An_Example(FishNumber as Integer)
Dim S as long
Dim ReceiverNumber as long
Dim ReceiverName as string
Dim MJD as long
Dim Lattitude as single
Dim Longitude as Single

For S=0 to FishDatabase.NumberOfStamps(FishNumber)-1         '0-base
      'Get the stamp
      FishTable.ReadStamp FishNumber, S
      'The STAMP variable now contains the information
      'I did this because VB was too stubborn to easily accept a user-type as
      'a function output. Now I know that you just need to make the
      'sub/function a "Friend" but w/e…

      ReceiverNumber=Stamp.Site

      'This will return the group name if it's in a group!
      ReceiverName=Receiver.ID(ReceiverNumber)
      'get the latitude/longitude
      Latitude=Receiver.La(ReceiverNumber)
      Longitude=Receiver.Lo(ReceiverNumber)


      'Get the date and make sure its valid
      If Stamp.Valid Then MJD=Stamp.Date
      'Draw the receiver
      Receiver.Show ReceiverNumber
Next S

End Sub
```

That was easy! You are welcome to add any analytical tools as long as you follow the database and object models I have laid out…