Session IV- Part A

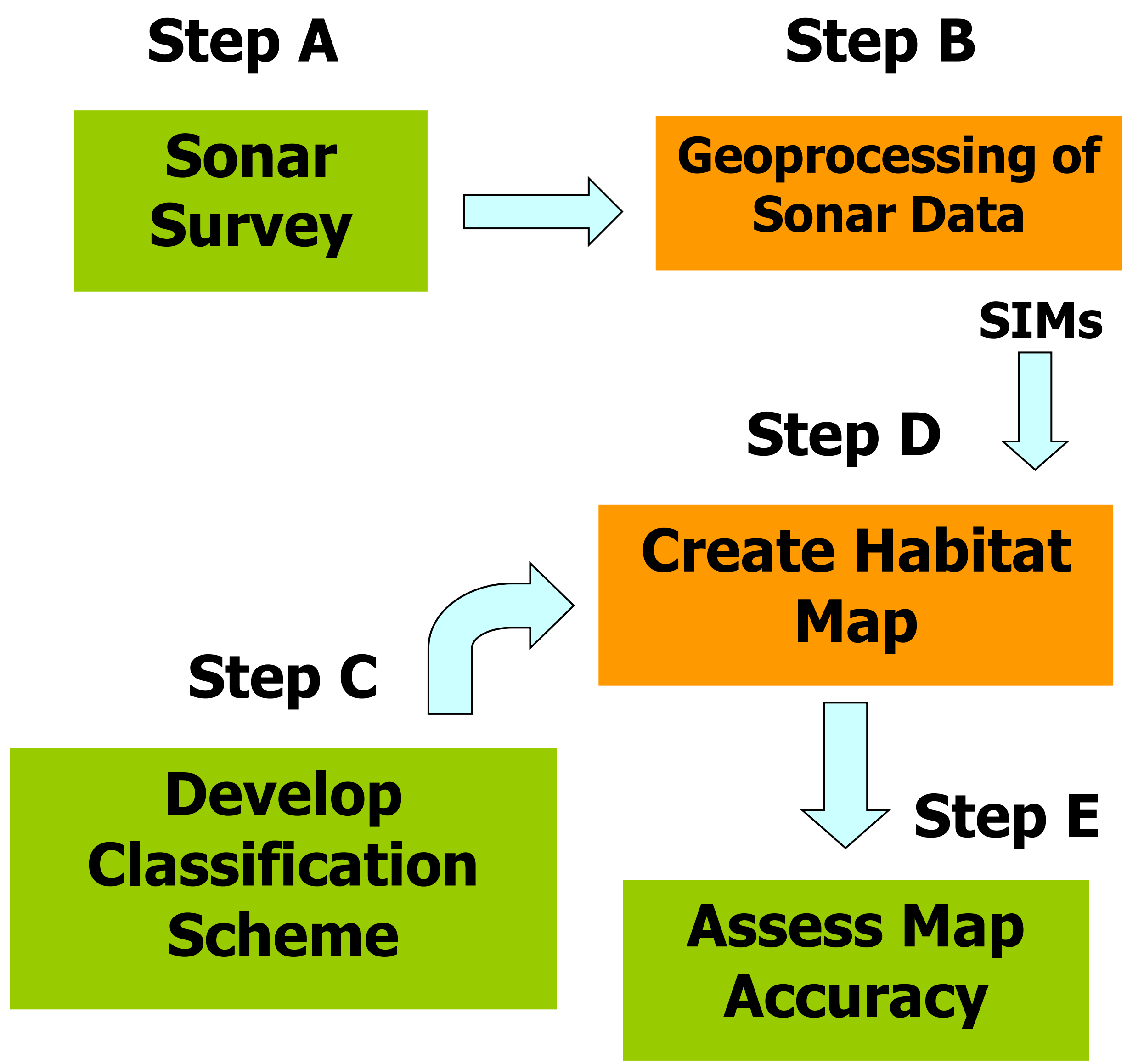
Our sonar image map layers are prepared, and we have inspected image quality and fit. We're finally ready to put our skills of image interpretation to good use in the development of classified habitat layers.

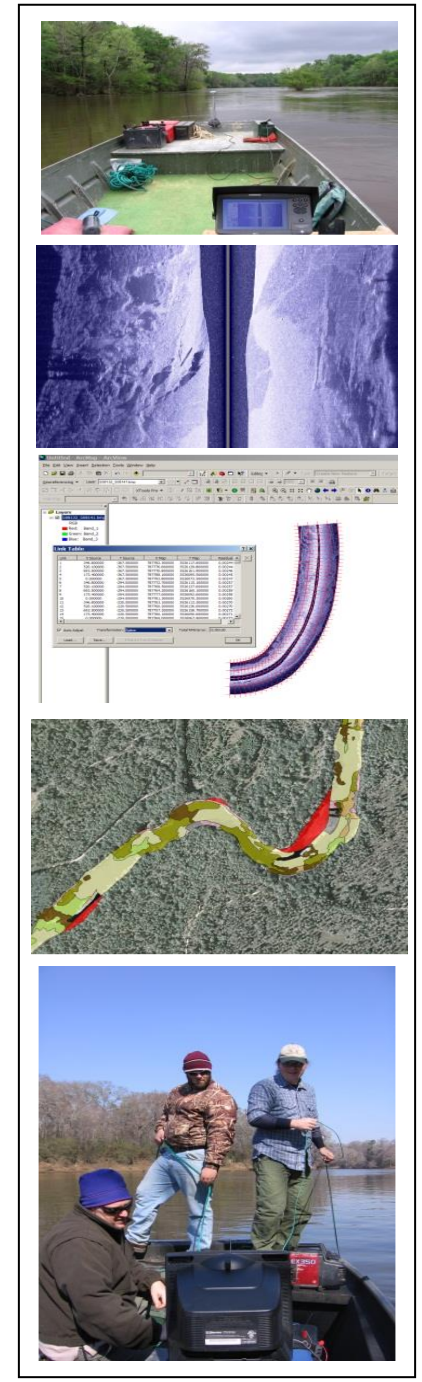
Mapping Habitat

The Mapping Process

5 Primary Steps

The development of sonar-based habitat maps is basically a 5-step process as illustrated in the adjacent flow diagram. Steps A, C, and E in green are steps that involve field work, whereas steps B and D, geoprocessing and mapping, are computer based. Step C, developing the classification scheme, is one that can occur earlier in the process. In fact, this may be the first step to undertake when planning a sonar mapping study- the identification of the unique habitat features to be classified. Step E, assessing the accuracy of the map, is one that should occur after the habitat map, or some portion of the map, is complete.





What will the map show?

A variety of habitat feature layers might be developed for display in the sonar-based habitat map. What to include will depend on the objectives of the map project. We typically begin a project by working on a draft of the substrate classification scheme using existing knowledge of the study system, and refine the scheme upon review of the sonar image data. Once the classification scheme is set, we begin the process of digitizing stream banks, then proceed to the delineation of visually-unique, substrate class signatures. At a later stage we bring in depth data, and add a layer for large woody debris if appropriate.

Habitat Elements to Map

In order of operation:

Develop classification scheme

1) **Stream banks**

2) **Substrate classes**

3) **Depth**

4) **Large Woody Debris**

Defining the scheme

The classification scheme represents the unique habitat feature classes that will be delineated and identified on the map.

The classification scheme must define mutually exclusive classes, and should be set prior to map production. In some cases, however, a unique sonar signature may be identified during image review that cannot be identified with existing knowledge. In such cases, a class can be created in the scheme to account for the unknown signature (e.g., unknown A), and groundtruth data acquired at a later date can be used to appropriately define and reclassify the class (i.e., unknown A= hard clay outcrop).

There is a lot of flexibility inherent in the development of a classification scheme. How many classes to include will depend on a variety of factors like the overall heterogeneity of the system. We have found it helpful to consider hierarchical schemes that can later be decomposed into fewer, more general classes. This approach is especially useful if the ability to accurately discriminate among several similar classes falls short of target expectations.

The Classification Scheme

- the unique feature classes we will attempt to delineate on the map

- Define mutually exclusive classes prior to map production
- How many classes to include depends on factors such as: system heterogeneity, project objectives, image resolution, time available, interpreter experience
- Consider hierarchical schemes that later can be collapsed into fewer, more general classes

Developing the scheme

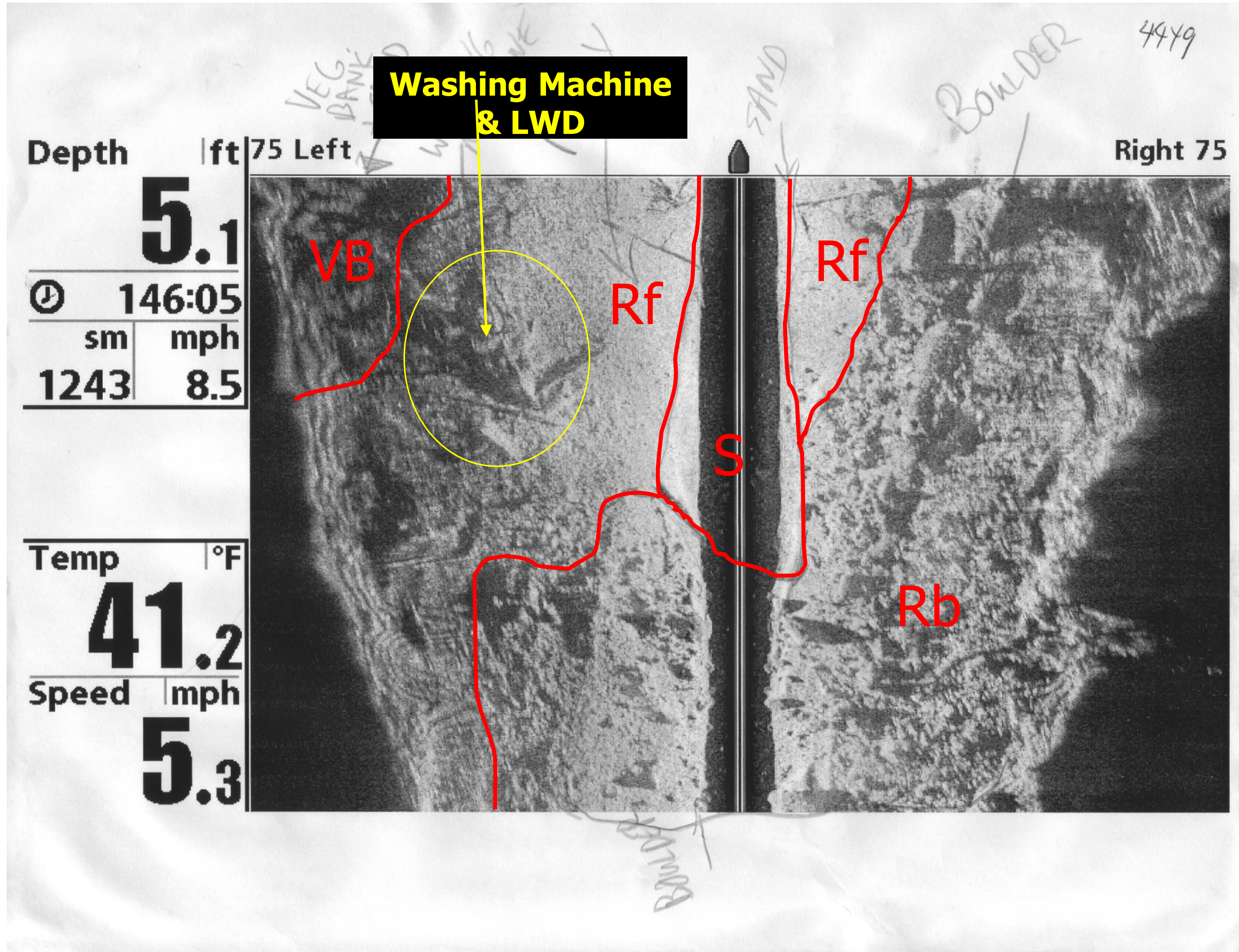
There are various strategies for developing the scheme. To develop our skills at image interpretation, and to develop a classification scheme to be used in streams of our work region, we captured imagery in several reaches, selected images that exhibited the common and predominant sonar substrate signatures, and prepared a printed version of the images for ground-truth inspection in the field during low, clear water conditions. In this example, our technician Wes Tracy is inspecting a printed sonar image from the exact area of the river where it was obtained. These images can be annotated, and serve as a guide when developing and implementing the classification scheme.

The Classification Scheme

Developing the scheme

Here is an example of a printed sonar image that was annotated in the field during a groundtruthing expedition. The codes refer to classes in the scheme (e.g., Rb= Rocky boulder). In this case, we delineated an area of vegetated bank in the upper left corner of the image. This class did not appear in the final scheme as it was either very rare, or the vegetation itself did not exist at the time of the sonar survey. We also happened to find a washing machine among some logs in this reach.

Inspecting Sonar Images



Printed images are annotated in field

The scene from this image

This photograph was taken of the area shown in the previous sonar image printout. The field of boulders in the foreground is obvious. Looking across the channel we find the position of the washing machine, and the vegetated bank beyond the appliance.

Inspecting Sonar Images

The scene from this image

This is the view from the other side of the channel. Turns out, the washing machine was hanging out with a few deadheads.

Inspecting Sonar Images

What is the MMU?

Along with the classification scheme, a minimum map unit should be defined prior to map production. The minimum map unit, or MMU, is the smallest areal extent that the map maker will attempt to delineate on the map. The size of the MMU will likely be influenced by the classification scheme. A very detailed scheme, developed for a heterogeneous system, may have a smaller MMU relative to a simple scheme containing only a few classes. The MMU will likely also be influenced by overall image resolution. Thus, systems scanned at lower range settings may be assigned smaller MMUs during map production. In our experience, the typical size and shape of the predominant substrate patches has dictated the MMU used in projects.

Minimum Map Unit (MMU)

- **The smallest unit of area to attempt to delineate on the map**
- **Influenced by classification scheme (and the factors influencing the scheme), time available for mapping**

MMU for Lower Flint River

In our lower Flint River map study we adopted a MMU of 314 m^2. This area can be represented by a circle with a 10-m radius. In the adjacent photograph we laid a measuring tape across an area of rocky boulder habitat at a length of 10 meters to illustrate the MMU adopted in this project.

This photograph also serves to make a point regarding substrate classifications. In nature, it is not uncommon to find mixtures of substrates in a patch, yet often one substrate type is predominant. The classification scheme should define what is meant by predominant. In this habitat patch, we find boulders in a matrix of cobbles, gravels, and sand. The classification scheme developed for this project dictated that boulders would be considered the predominant substrate if 3 or more boulders, each within 1.5 meters of the next adjacent boulder, covered an area equal to or greater than the MMU. The smaller length of visible tape near the gheenoe is 1.5 meters long. Although the substrate is clearly not 100% boulder composition in this patch, we would have classified this patch as boulder substrate in the habitat map.

In the scheme for this map we also created a class for mixed substrate composition. Mixed patches were any areas that did not have any one substrate class predominating within an areal equal to the MMU.

MMU Example

MMU Lower Flint River= 314 m^2, area of 10-m radius

Inspecting polygon area

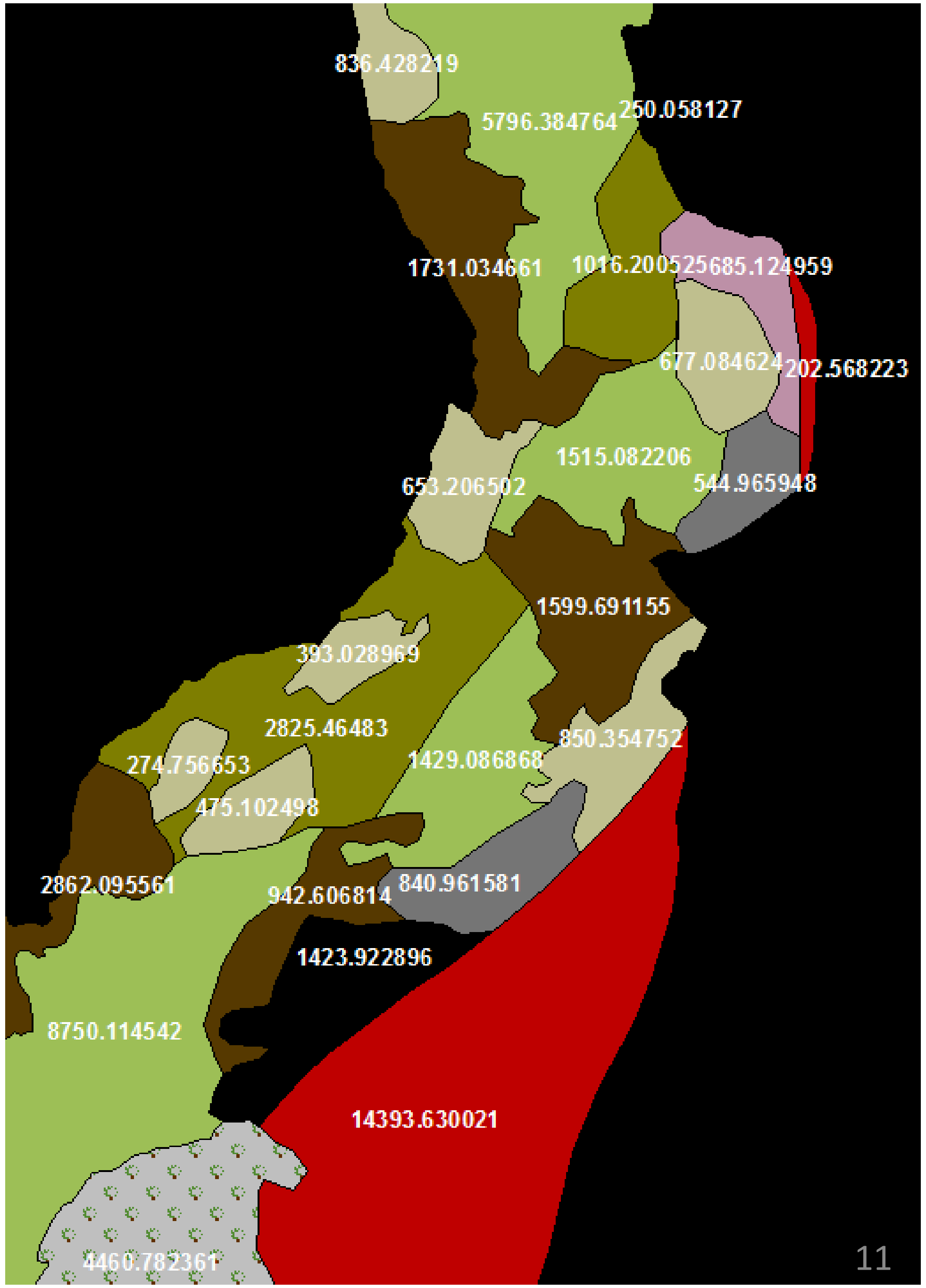
When a draft of the substrate map is complete, it is possible to inspect and edit the map for adherence to the specified MMU. In the example provided here, there are a two polygons that did not meet the MMU; a red polygon representing an area beyond sonar range (i.e., no sonar data) that is 202 m^2 and a yellow polygon representing a sandy patch 274 m^2. We could either decompose the sand polygon into the surrounding mixed rocky class (olive color) or adjust the MMU downward for compliance.

It would be less appropriate, however, to decompose the 202 m^2 polygon into either the pink or grey substrate classes, as these represent areas of uncertainty that were within sonar range during the survey. To preserve the integrity of the accounting system built into this particular classification scheme we would have preserved the 202 m^2 polygon in the final map.

Checking the MMU

LFR MMU-

314 m^2



Common substrates

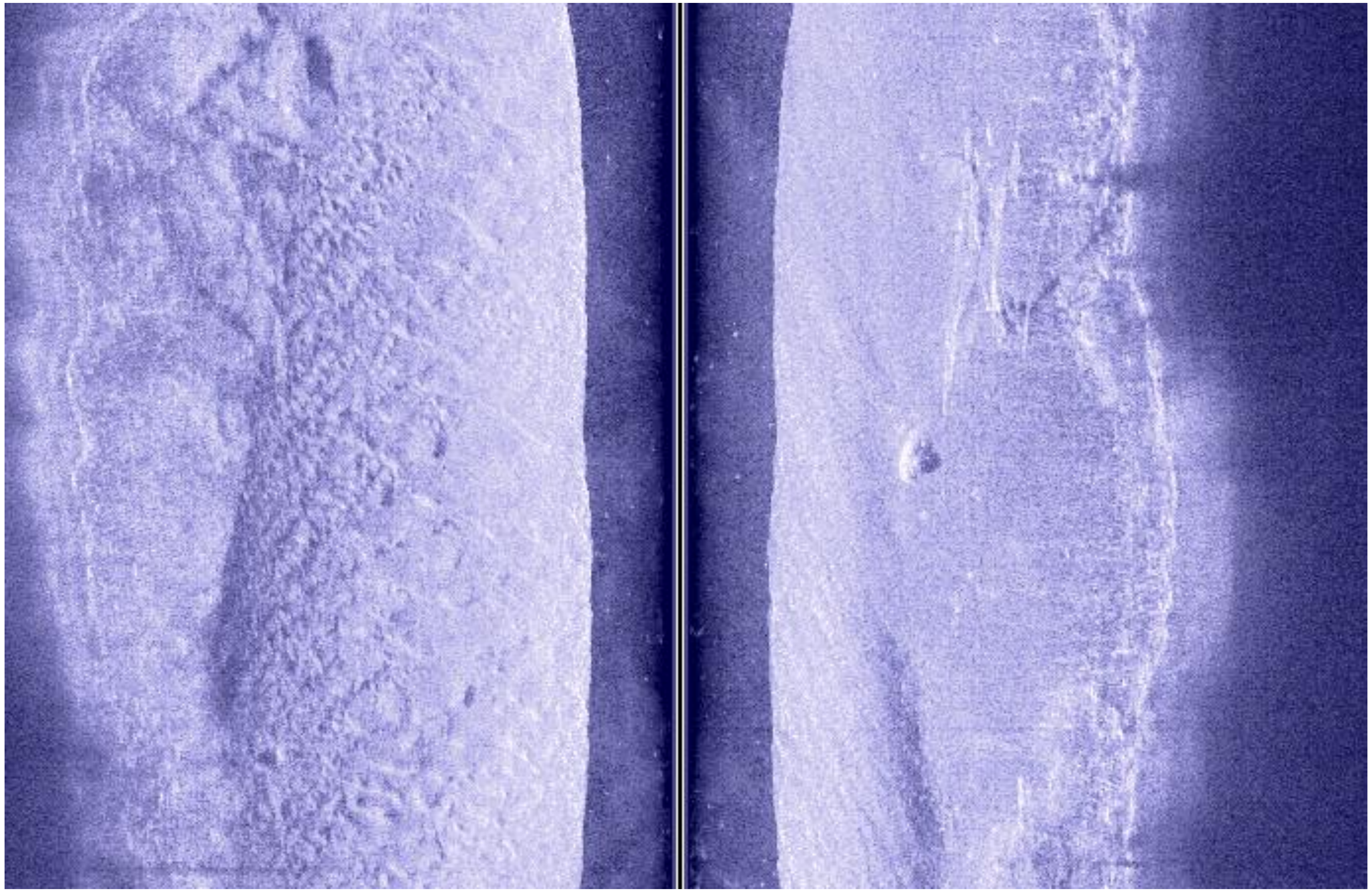
Let's turn our attention to some of the common substrate classes that appear in streams of our work region. Sand patches often exhibit ripple and dune patterning. These textures produce clearly recognizable sonar signatures when scanned. As this photograph illustrates, sand can also exist in plane bed form. Whether sand patches are rippled, dune-like, or plane bed is related to stream velocity and other forces acting on the stream bed.

Classes Identified for Mapping

Common substrates

Here is a decent example of a predominantly sandy reach that exhibits both rippled and plane bed texture.

Sandy (S)



Coarse substrates

It is not uncommon in streams of Southwest Georgia to find coarse rocky substrates. In this photograph we find cobble, which we describe as rocky fine in our classification scheme, and boulder, called rocky boulder in the scheme. It's easy to visualize a line that defines the edge separating boulder from cobble substrate in this patch.

Rocky fine (Rf)
Rocky boulder (Rb)

Coarse substrates

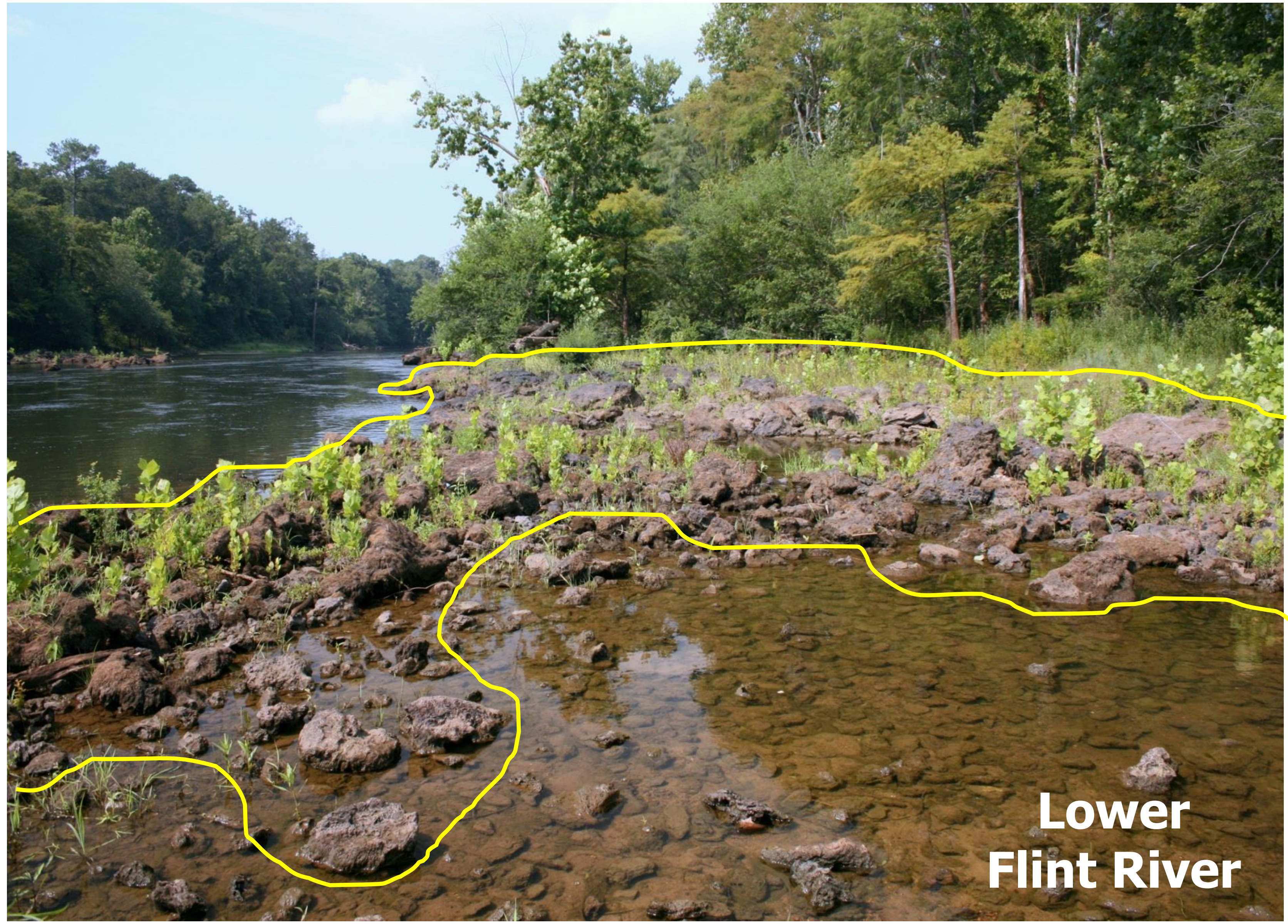
These photographs provide a couple more examples of substrate patches predominated by cobble (rocky fine) substrate in a larger river system.

Rocky fine (Rf)

Coarse substrates

In many reaches of the lower Flint River, boulders were dredged from the river bed and deposited in piles along the river margins to aid in navigation. This photograph provides another good illustration of the dividing line between rocky boulder and rocky fine substrates in this river system. The digitization of boundaries between apparent substrate classes in sonar imagery is the same as drawing the yellow lines that define the substrates in this photograph.

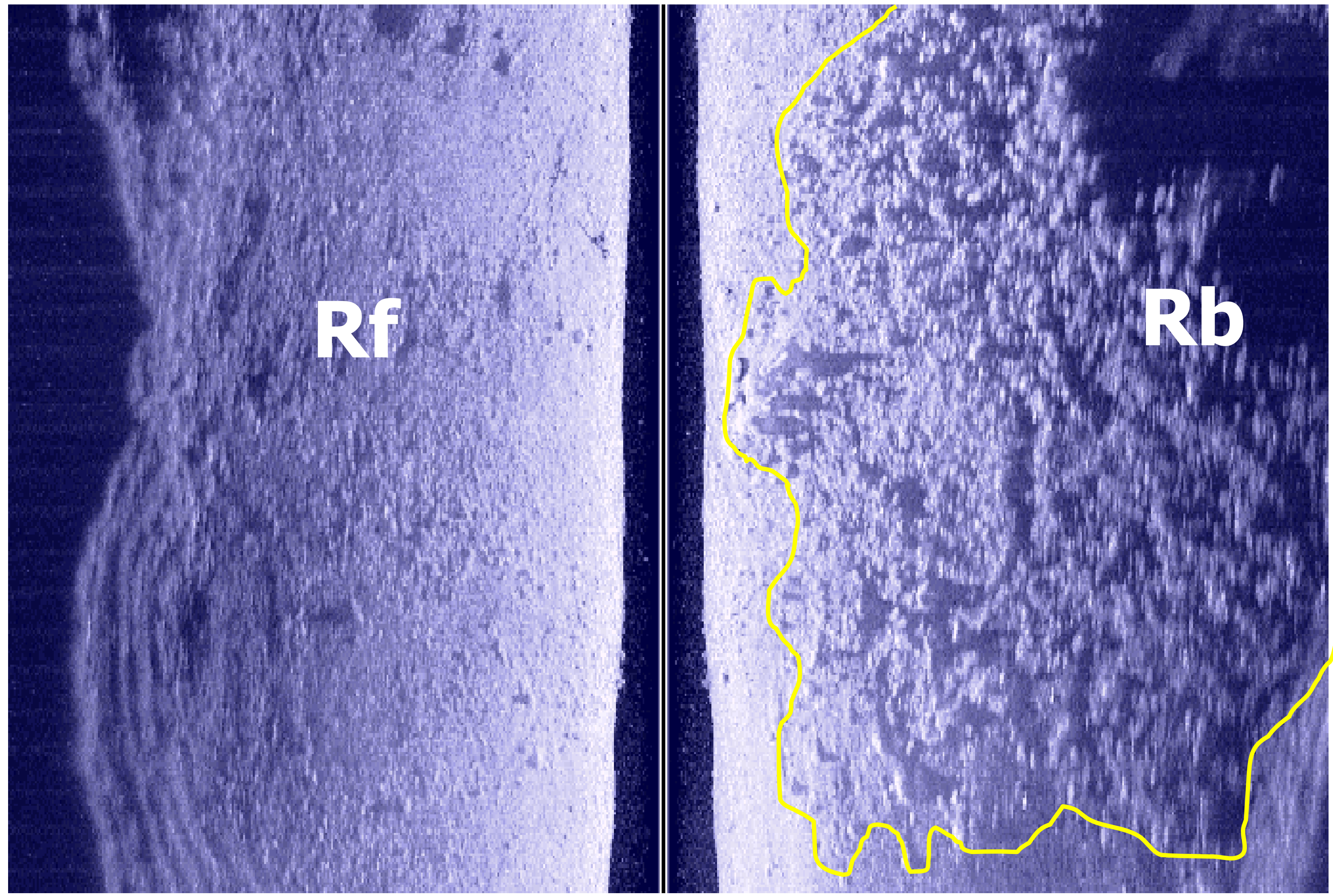
Rocky boulder (Rb)



Sonar signatures

This sonar image provides an excellent example of the difference between boulder (Rb) and cobble-pebble-gravel (Rf) substrates in a Southwest Georgia creek. This image was created using a range of 85 feet per side. The boulder outcrop exhibits larger particles and more sonar shadowing, whereas the cobble (rocky fine) material is of smaller diameter- the stream bed appears roughly textured rather than smooth or rippled.

Rocky fine vs Rocky boulder



Smooth limestone bedrock

Another common substrate we have encountered is limestone rock. Limestone appears as smooth bedrock exposures, as seen in this photograph, or in coarsely fractured, boulder-like outcrops. In this scene, the fine silt that had accumulated on the bedrock surface was cleared away to reveal the greenish hue of surficial periphyton.

Limerock fine (Lf)

Ichawaynochaway Creek

Smooth limestone bedrock

Here is another look at a smooth limestone bedrock exposure, a substrate class we have called limerock fine in several publications. One of the characteristics that helps to identify this substrate in sonar imagery is the fractures that often occur throughout the substrate. It is very difficult to obtain good photographs of these fractures as they are almost always underwater, although small fractures are visible in the limestone exposure seen here. Larger fractures accumulate gravel and sand, and reflect the sonar signal differently than the surface of the limestone exposure, thereby producing a sonar signature that reveals the fractures.

Limerock fine (Lf)

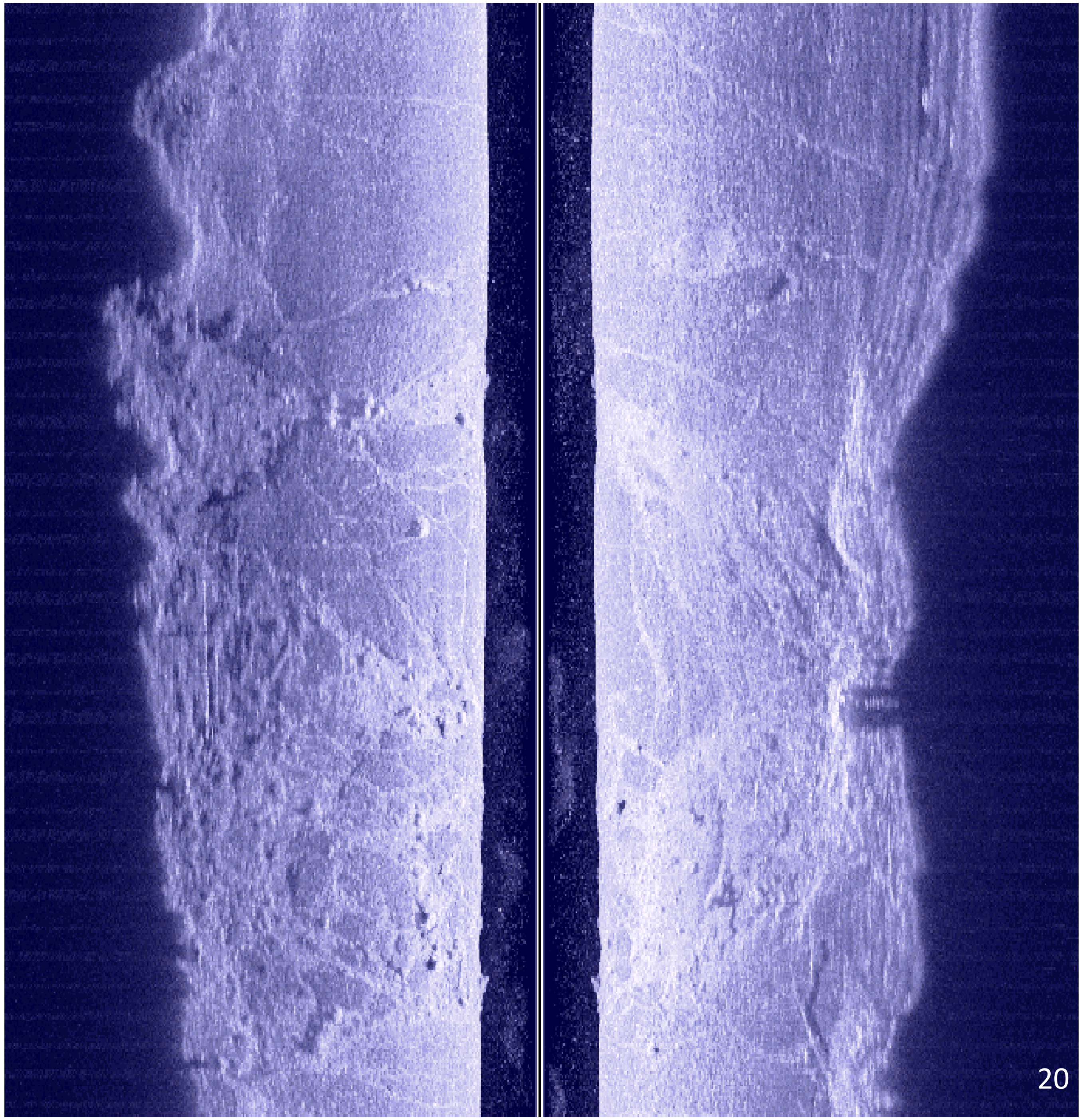
Lower Flint River

Smooth limestone bedrock

This raw image mosaic provides an excellent example of a river reach that is predominantly smooth limestone bedrock. The fractures throughout the limestone are clearly evident here. In our experience, limestone bedrock has a darker tone (color shade) in sonar imagery than sand or rocky fine substrates. And thus, the combination of texture and tone help to discriminate smooth limestone bedrock from other substrate types.

- **Sometimes fractured**
- **Darker tone than sand or rocky fine**

Limerock fine (Lf)



Coarse limestone boulders

In our work area, limestone also commonly appears in outcrops of large, fractured, boulder-sized chunks. To discriminate this form of limestone from the smooth bedrock exposures we have just examined, we assigned a class called limerock boulder (Lb) in our map classification schemes.

Limerock boulder (Lb)

Ichawaynochaway Creek

Coarse limestone boulders

In some places the limestone boulders can be massive. Here, boulders are perched atop a limestone wall that drops almost vertically to the riverbed below. At the base of the wall are submerged limestone boulders.

This is a great place to find large flathead catfish! The boat ahead is our catfish shocking boat; in my other hand is a net ready to snatch the rolling lunkers.

Limerock boulder (Lb)

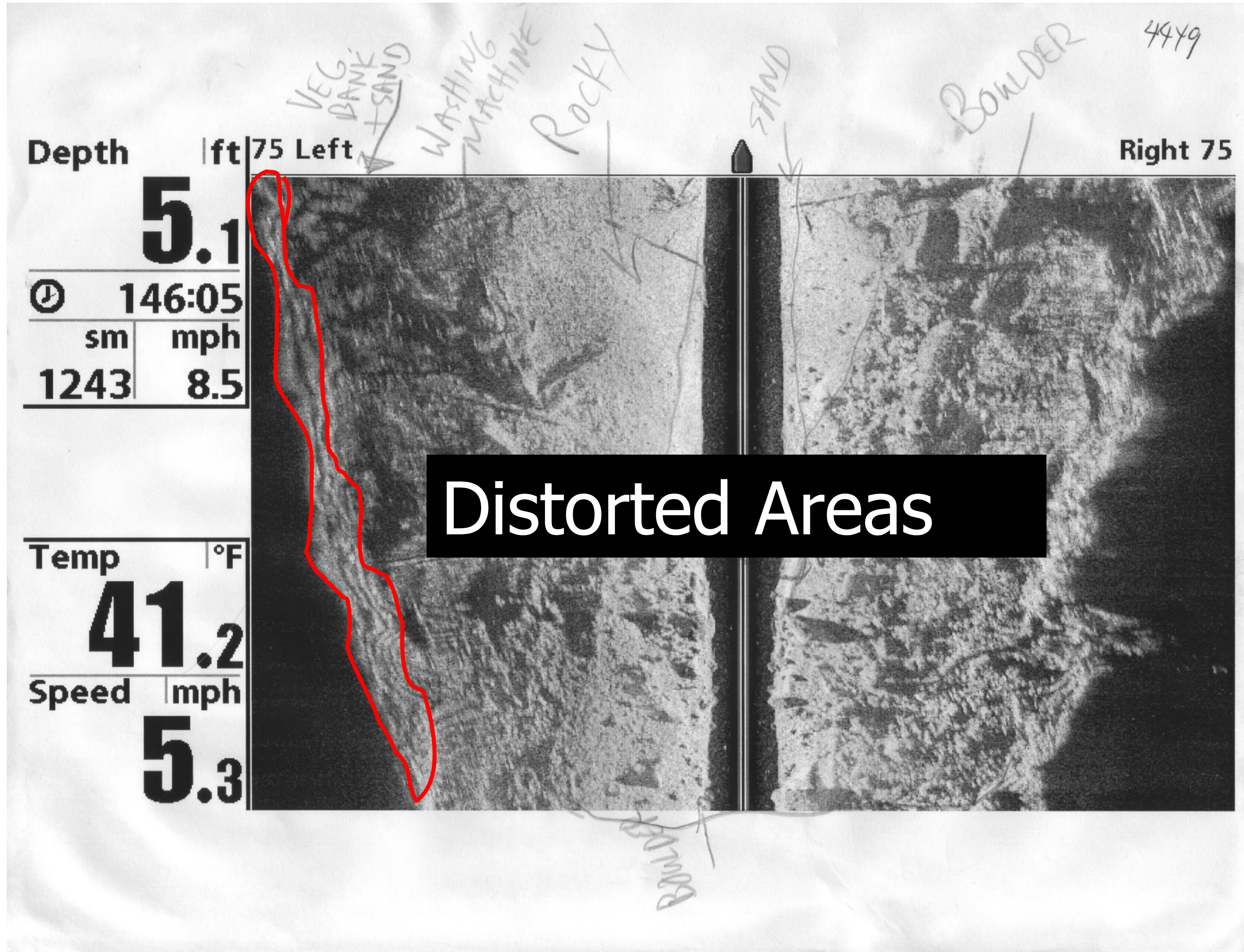
Lower Flint River

Accounting for uncertainty

It is not uncommon for areas near the margins of the sonar image, or near the banks, to be somewhat distorted. This effect can at least be partly attributed to beam spreading in the far-field, as explained in Session I. Another cause of distortion along the banks can come from the increase in slope as the channel rises to the edge of the bank. Recall that side scan sonar performs best over relatively flat terrains; signal returns coming from a steeply sloped bank will be compressed into a narrow region of image space relative to returns from a flat portion of the channel. Regardless of cause, there are ways to deal with areas of image distortion when preparing a sonar-based habitat map. In past projects we have included a class called "unsure" to represent areas that are difficult to classify due to distortion. It seems prudent to include such a class to account for map uncertainty. In the end, the amount of uncertainty is quantifiable, and uncertain areas are spatially identified. Targeted groundtruthing can be conducted to resolve uncertain areas if deemed necessary.

We have experimented with breaking the unsure class into 2 components- unsure sandy and unsure rocky- by classifying distorted areas as either predominantly sandy or predominantly rocky based on available image information, and contextual information such as whether the area was adjacent to a sandy flat or rocky shoal. This approach has yielded mixed results, see Kaeser and Litts (2010) and Kaeser et al. (2012) for details.

Unsure classes (US, UR)

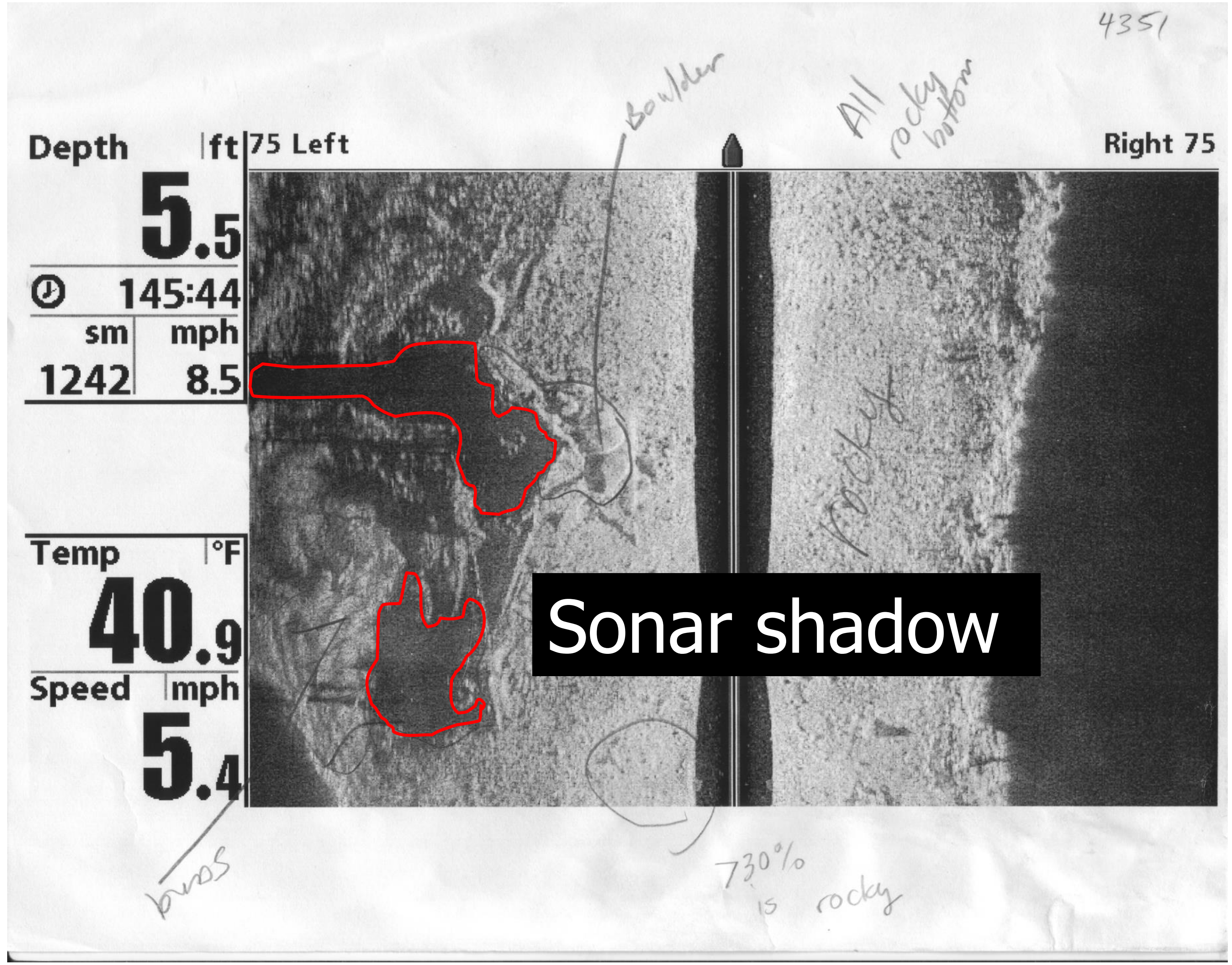


Accounting for shadowing

Areas covered by sonar shadow that cannot be assigned to a substrate class can be digitized and classified as "sonar shadow". Using a separate class for sonar shadowed areas allows us to quantify this type of data loss. On the other hand, shadowed areas can sometimes be accurately classified using contextual information or other data sources such as air photos.

*This annotated sonar image printout is another fine example of the field work undertaken to become familiar with predominant substrates of the region and their sonar signatures.

Sonar Shadow (SS)



Examples of other classes

This list represents some of the classes that have appeared in other mapping projects we've conducted. This list is by no means comprehensive. We suspect a variety of substrates we haven't yet seen to exhibit unique and distinguishable sonar signatures. A worthy goal is to evaluate the accuracy of mapping such substrates with low-cost, side scan sonar.

We have used the class "No data beyond range" to identify all portions of the wetted stream channel that were beyond the range of the sonar during the survey (thus no image data available). A reliable air photo that shows the wetted channel at flows comparable to those experienced during the survey is necessary to accurately digitize these areas. Likewise, air photos are useful for digitizing the boundaries of mid-channel islands, especially if survey navigation of side channels was not undertaken.

Additional Classes

- **Mixed rocky**
- **Bedrock outcrop**
- **Coarse sand/Gravel**
- **Clay outcrop, Claystone**
- **No data beyond range**
- **Island**
- **Vegetated Bank**

Both art and science

With the processed sonar image maps in hand, and the classification scheme set, we're ready to begin the process of creating the habitat map. This process is not much different than the cartoon illustration of the map maker at the table, hand drawing a map. Habitat features are delineated (i.e., digitized) by hand (with a mouse) through visual interpretation of the sonar image map layer.

The human map maker is not an automaton, and maps produced by different map makers with different skills sets may be different. Two maps of the same area may be different, and yet still be useful and serve a common underlying purpose. The potential subjectivity inherent in the mapping process is a criticism we've heard voiced. However, unlike an automated computer program, the human map maker brings a complex set of skills that includes intuition about the imaging process, the relationship between river geomorphology and sediment deposition, experience with the system, prior mapping experience, and such to the task of interpreting and digitizing features within a complex form of imagery. Map creation is thus, by necessity, both an ART and a SCIENCE, and demands both skill sets from the map maker.

Creating the Habitat Map

Intuition
River Morphology
Field Experience, Notes
Supporting layers (e.g., air photos)
Field photos
Prior mapping experience

Feature delineation largely by visual interpretation

Truism #4- Map Creation is by necessity both ART and SCIENCE, and demands both skill sets

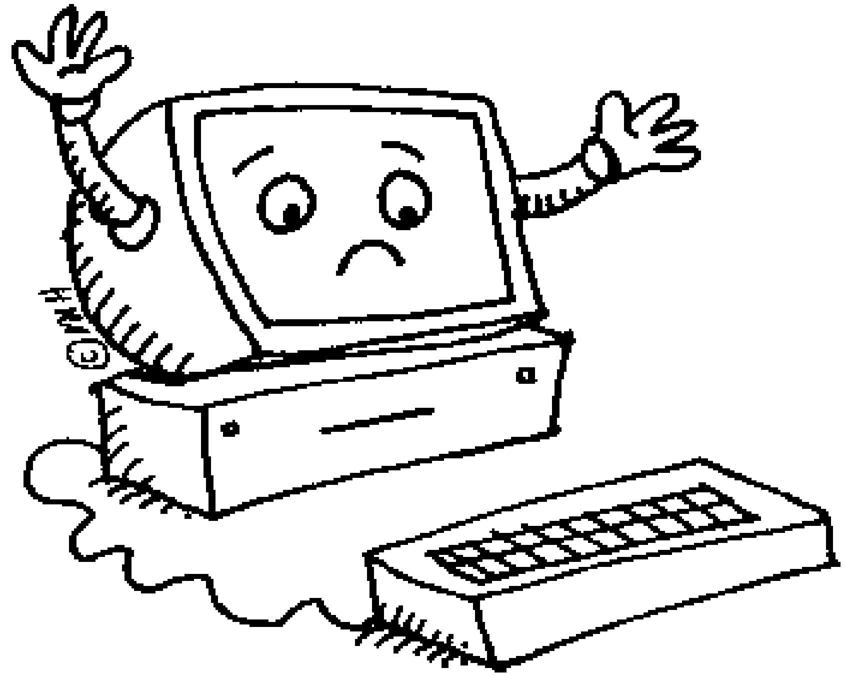
Can't my computer do it?

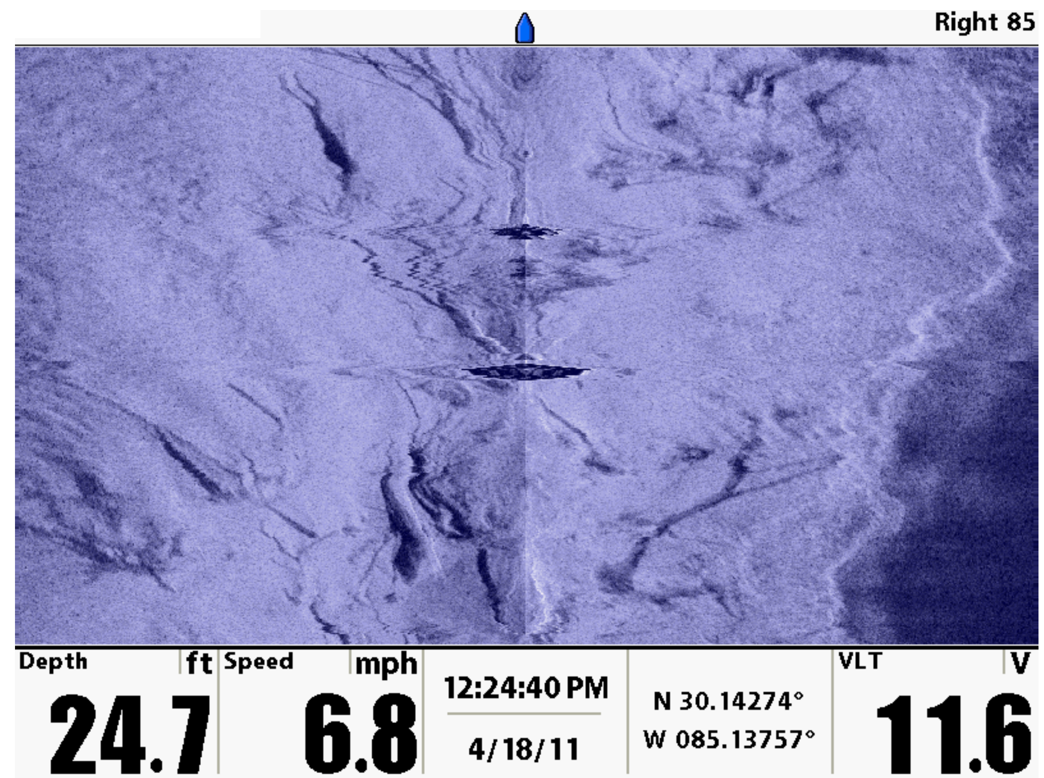
As sophisticated as computers are these days, it may come as a surprise that automated computer routines for classification of side scan sonar imagery are most likely not (currently) as effective as a trained side scan map maker. We touched on this issue at the beginning of our session on Image Interpretation. The computer obviously doesn't have the brain of the map maker, or the sense of intuition. What would the computer do upon encountering an image like the one on the right. We know this is woody debris, whose likeness has been distorted through ineffective slant range correction. How would we program the computer to recognize such things? Perhaps someday the computer will be as effective as the human side scan cartographer, but for now we are emboldened by the fact that computers simply can't do it better than we can.

For additional information- Acoustic Techniques for Seabed Classification (Tech Report 32) by Cooperative Research Centre for Coastal Zone Estuary and Waterway Management

http://www.ozcoasts.gov.au/geom_geol/toolkit/Tech_CA_sss.jsp

Auto-Classification?

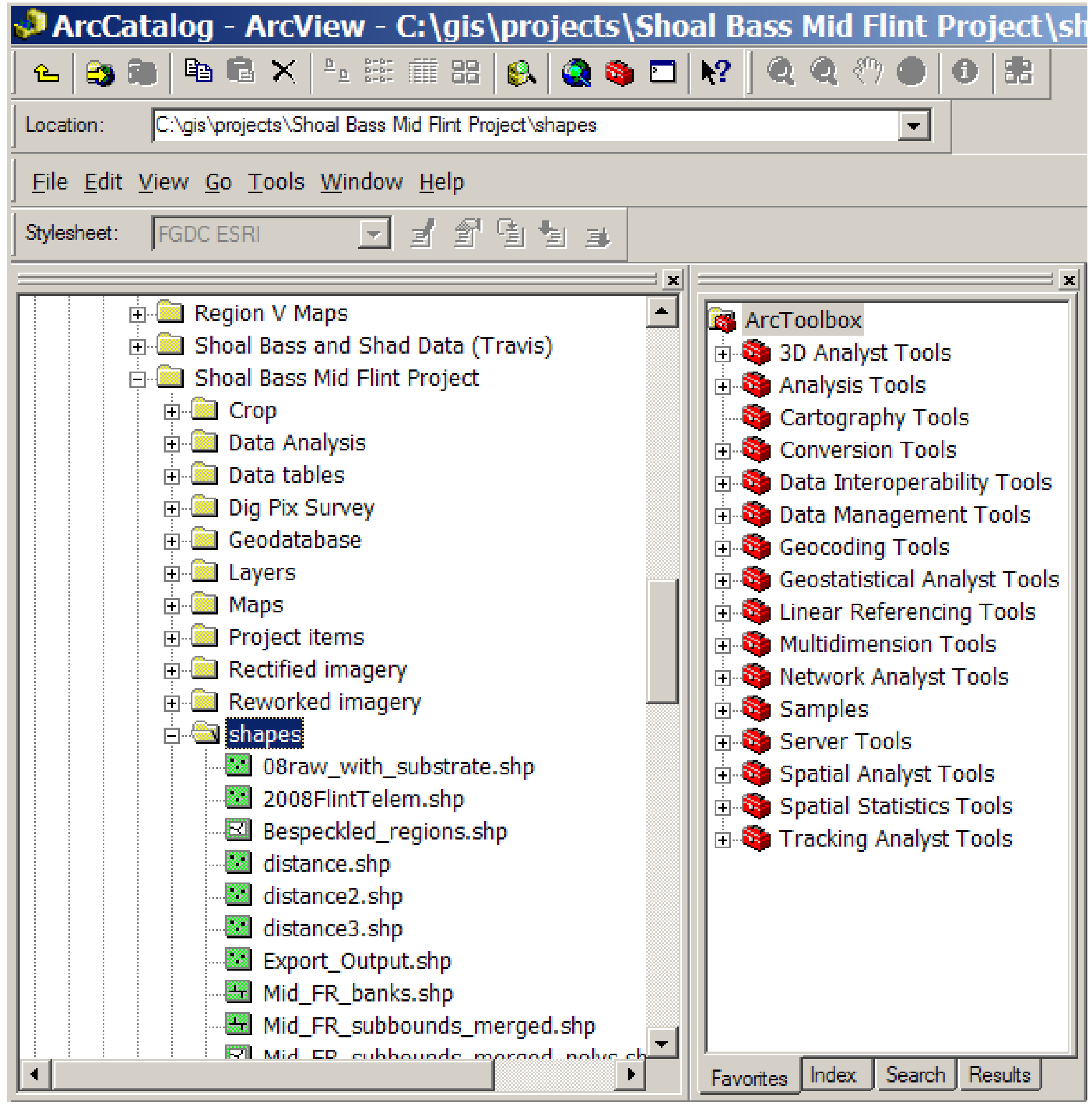




Start with bank lines

We typically begin all of the digitization work on a sonar habitat map with the drawing of stream or lakeshore banks. Begin by creating a new polyline shapefile using ArcCatalog.

Map Production



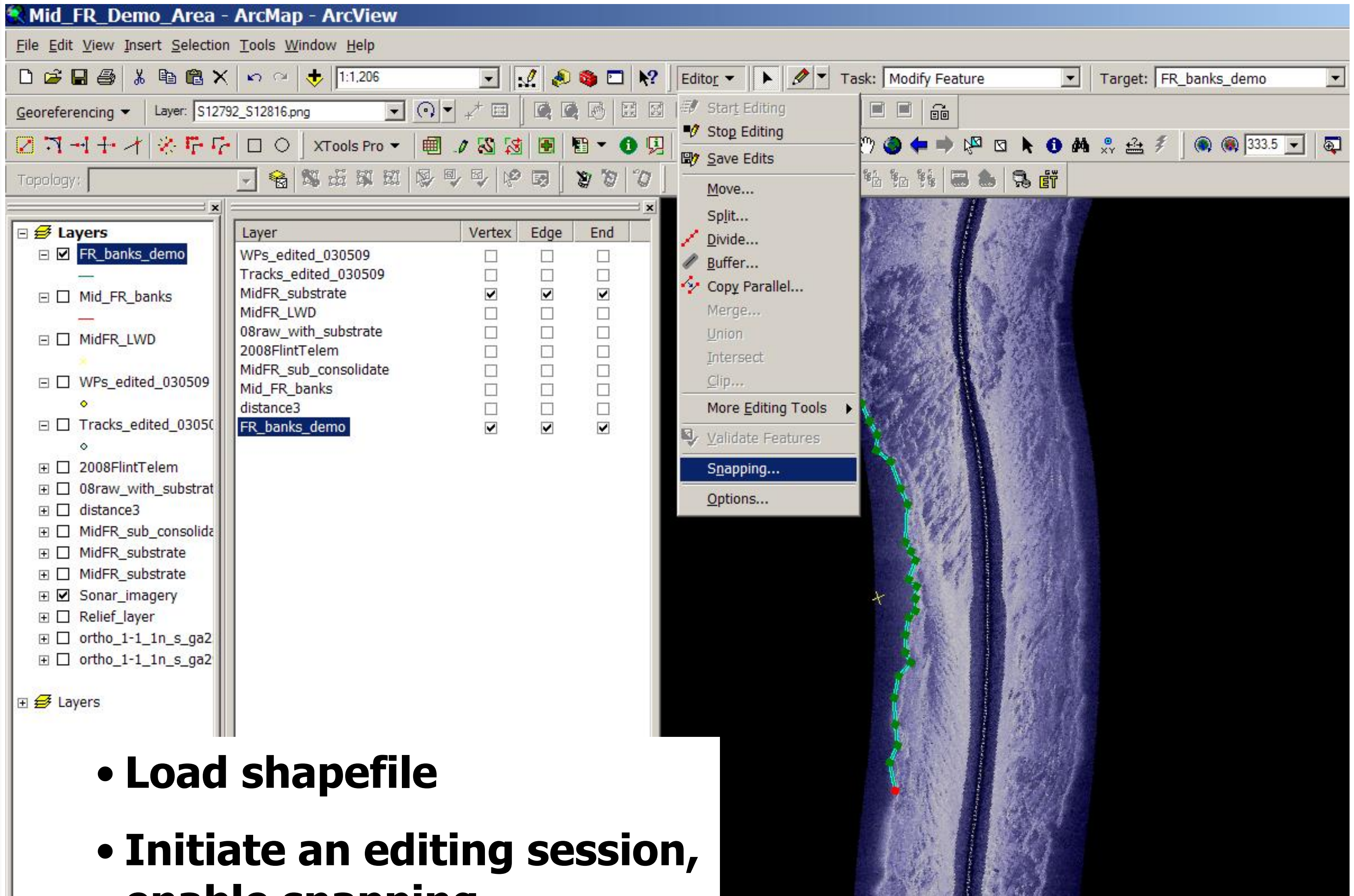
Enable snapping

Load the newly created bank line shapefile into the map project and project the file to the appropriate UTM zone. Initiate an editing session on the line, and make sure to enable snapping of ends for the polyline.

Snapping is so important during habitat map production, the topic deserves additional attention. Snapping enables the joining of two adjacent line segments. Joining adjacent line segments will be necessary whenever there is a break in the digitization process when working on bank (or substrate) lines. Without snapping enabled, it is quite possible to create a line segment that appears to be connected to the nearest segment, when in fact a very small gap exists between the segments. This gap may only be visible when zooming in at a very fine scale. Such gaps pose major problems later when line segments are merged, and the enclosed areas converted to a set of polygons. We wish to avoid such unwanted gaps at all costs, and do so by setting up and enabling the snapping options properly. Please consult the ArcGIS Help menu to learn more about snapping. In ArcGIS 10 the form of snapping of interest is called "classic snapping". This option must be enabled under the General Editing Options. Also consult the help menu to learn about "snap tips", and "sticky move" and "snapping tolerances".

With snapping enabled, we begin digitizing bank lines by zooming in to imagery at the appropriate scale and point-and-clicking our way along the bank margin to draw the line.

Stream bank digitization



- **Load shapefile**
- **Initiate an editing session, enable snapping**
- **Zoom to appropriate scale and begin digitizing**

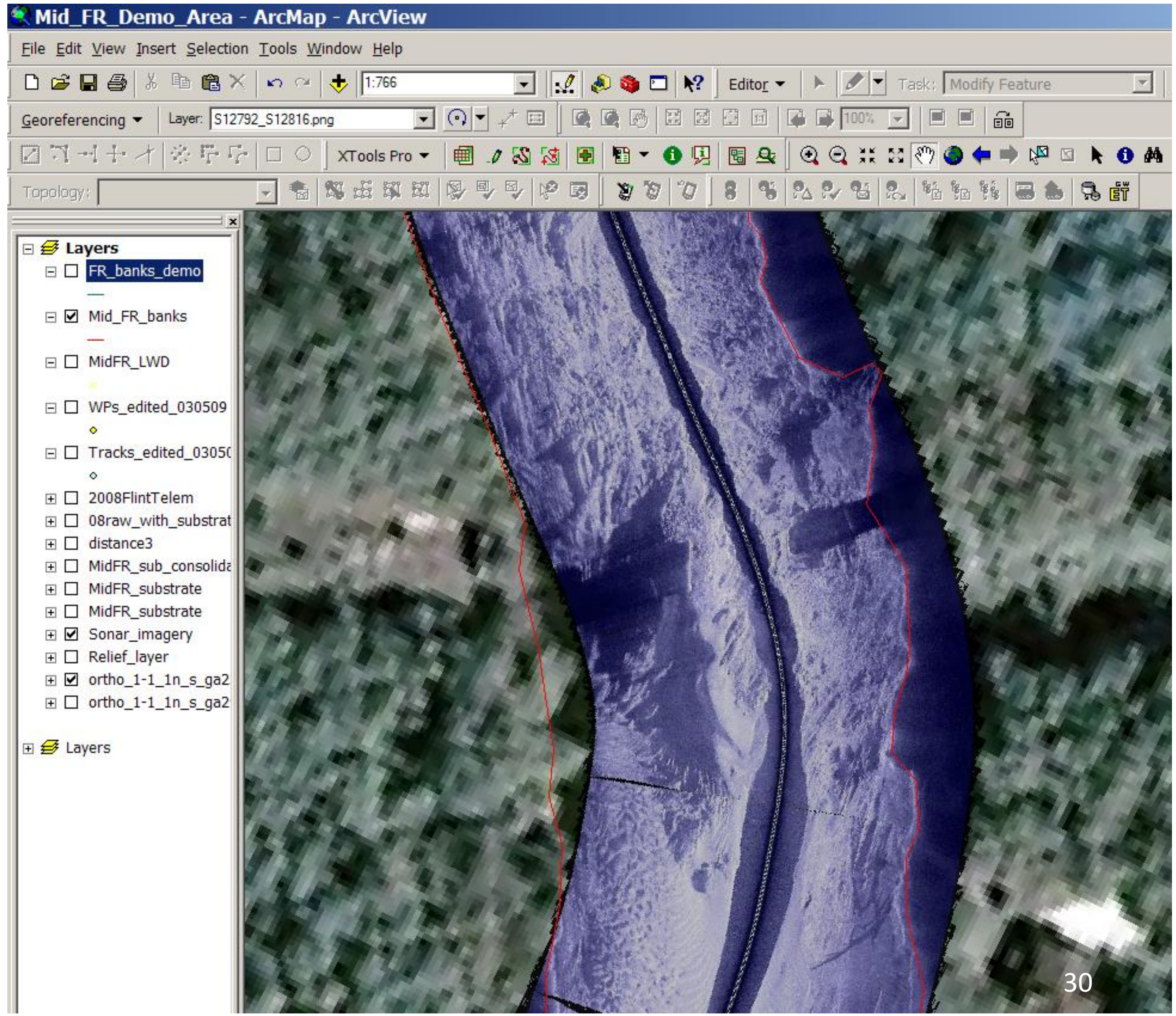
Banks not visible

Inevitably there will be discrete reaches of the river where banks are not visible in the sonar imagery because they were beyond range or concealed by sonar shadowing. In such cases we use an underlying air photo layer to aid in the digitization of likely stream bank position. Consider that trees often overhang the stream channel and obscure the actual bank from aerial view.

When the substrate map is complete, the area that exists between the out-of-range stream bank and the edge of the image layer will be turned into a polygon and assigned to the class "missing data/beyond sonar range".

- **Use aerial imagery to digitize approximate bank bounds in areas beyond sonar range**

Banks beyond range

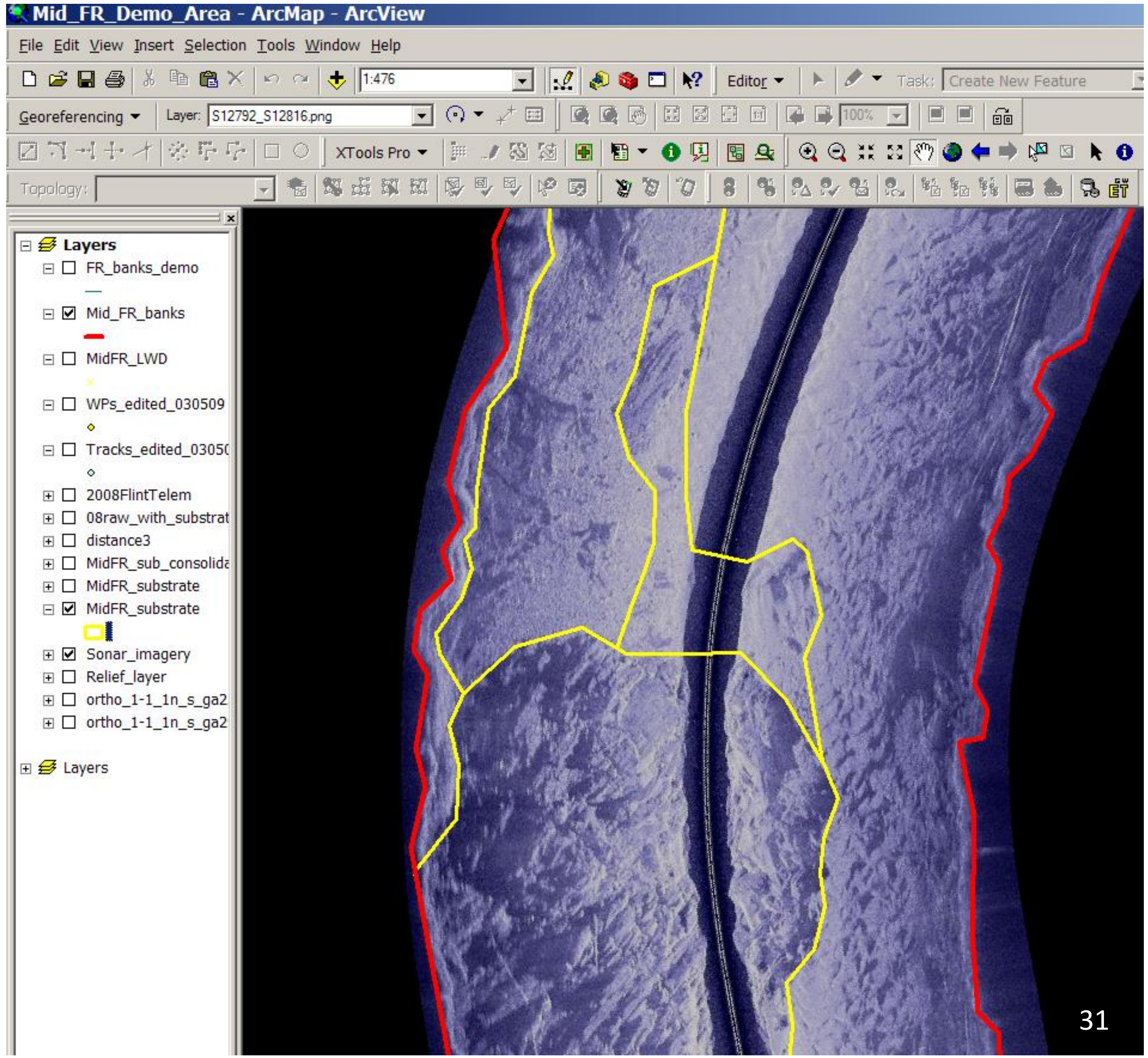


Substrate lines

Once bank lines are complete, we turn to the digitization of apparent boundaries between unique classes in the scheme. We recommend using a separate polyline shapefile for substrate lines; this line must snap to bank lines and other substrate lines. When digitizing, imagery is interpreted and lines are drawn as if the water column does not exist. This means that when a given substrate class is seen to extend across the water column and appear on the other side of the image, then the line bounding this substrate must do the same (see image at right). Consistency and adherence to the classification scheme are important principles at this stage.

- **Digitize substrate bounds as polylines**
- **Enable snapping with bank and other substrate polylines**
- **Digitize as if water column does not exist**
- **Be mindful of class scheme and MMU**
- **Be mindful of compression effects near water column**

Substrate Class Boundaries

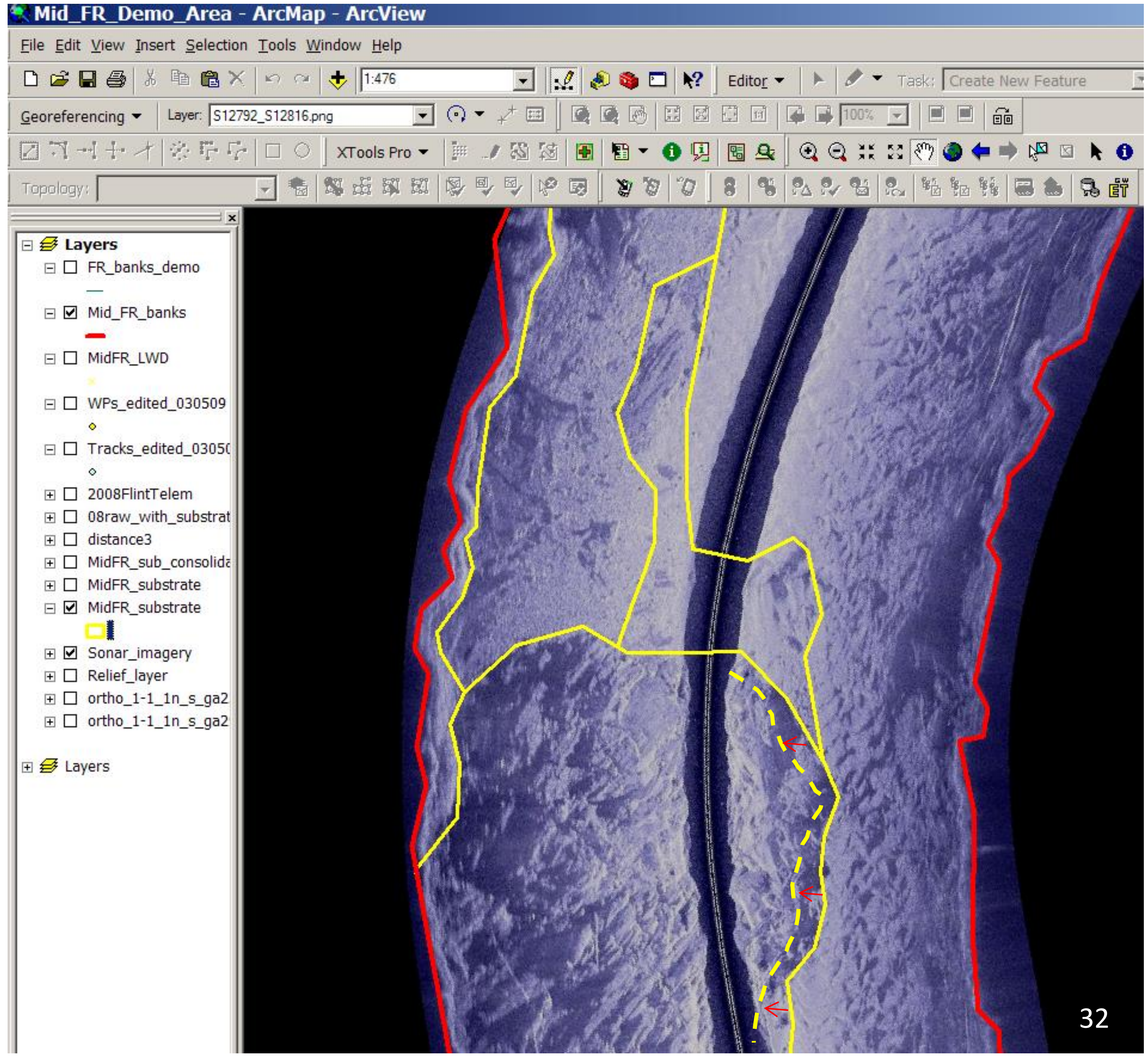


Spatial position of bounds

In practice, we always trace the apparent outline of the substrate patch when occurring either left or right of the water column, even though this introduces some spatial error. We find this practice to be the most straightforward and repeatable approach to digitizing from imagery that contains the water column. For example, the actual boundary of the bedrock outcrop below will be just left of the line we have drawn. In other words, if we had performed slant range correction during the survey, the edge of this outcrop would have appeared slightly closer to the boat path/image center. We have drawn a dashed yellow line to represent the real boundary of this outcrop. The spatial influence of the water column is greater for features closer to the image center, and the influence increases as the width of the water column increases.

When the water column represents a small proportion of the total image space (<10% of either side), the spatial error associated with tracing the apparent position of substrate boundaries in sonar imagery is minor. We deem this error insignificant with respect to the scale of the actual habitat patches in the map, and have demonstrated that high mapping accuracies are achievable when digitizing in this fashion. Nevertheless, if your aim is to achieve sub-meter accuracy for areal estimates of features, you may need to consider alternatives that involve survey-grade GPS equipment and in-stream work.

Substrate Class Boundaries



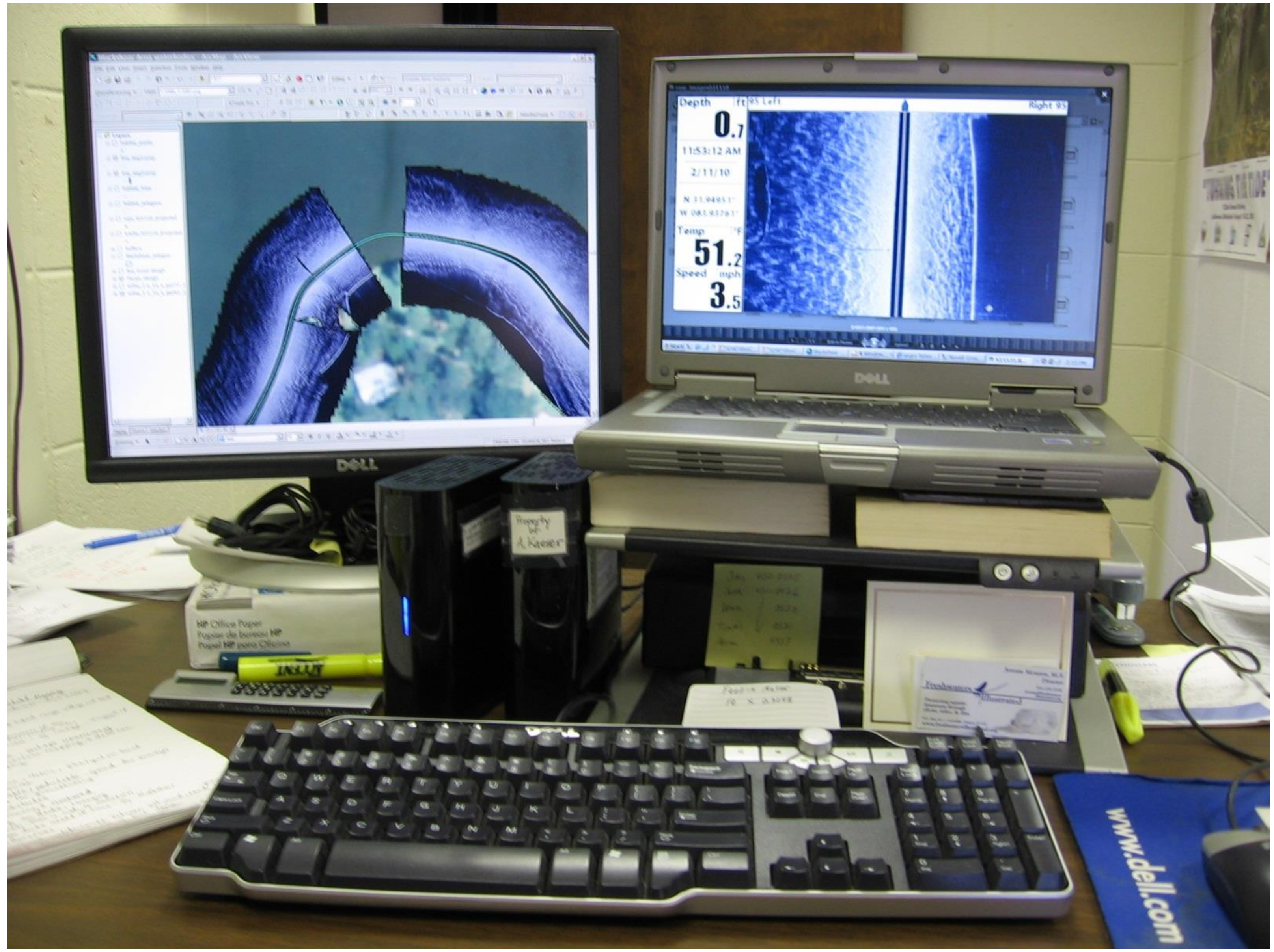
Raw images as reference

One of the benefits of the snapshot approach is the ability to easily reference the raw sonar image data set during the mapping process. The process of image rectification can sometimes slightly degrade image quality- after all, pixels are being rearranged to fit the image to its real-world shape. It's helpful to be able to quickly reference and retrieve the original raw image when confronted with a difficult-to-interpret area. The raw image sometimes helps to clarify the interpretation.

Raw images are referenced during the mapping process by overlaying the waypoint data set on the sonar image map layer. Each waypoint contains the raw image ID number that can be used to retrieve the image from the appropriate folder on an adjacent computer screen. Don't have dual screens? Well, if you plan to do much sonar habitat mapping, we highly recommend the dual screen set-up. The higher quality screen can be used to display the sonar imagery, and the other screen can be used to display your computer directory, ArcCatalog, Excel tables, or any other programs in use during the mapping process.

In the example provided on the right, we are showing the use of the raw image to interpret what was going on in an area where an image failed to rectify due to the boat turn. These issues can now largely be resolved using an approach Thom developed to correct warping and rectification failures (another benefit of the snapshot approach!).

Using raw images

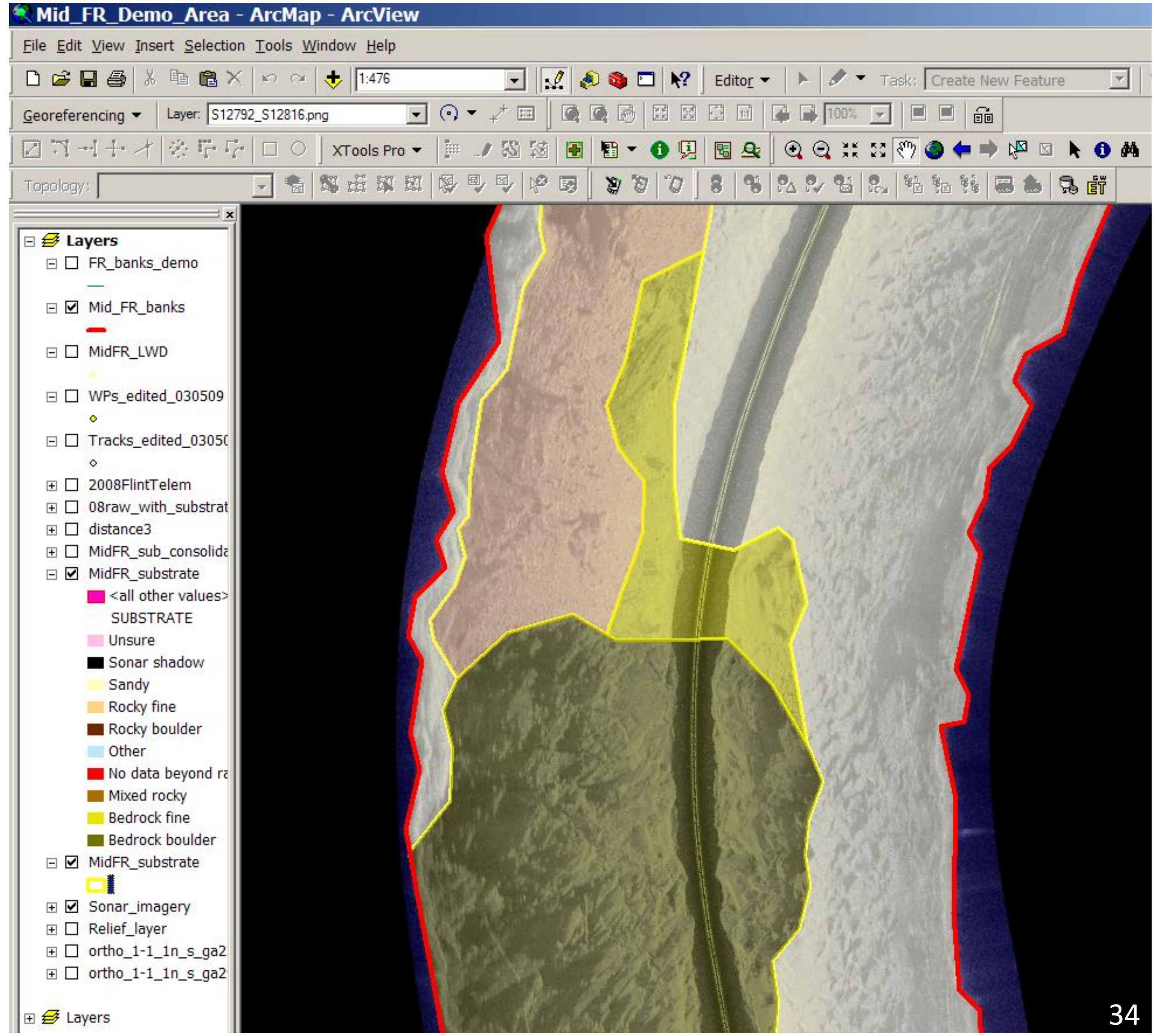


A substrate layer unfolds

Once all substrate bounds are complete, the substrate lines shapefile is merged with the bank lines shapefile. Using the Data Management Tools "Feature to Polygon" option under the Features tab (enabled at the ArcINFO level) all areas bound by polylines can be converted to polygons. We advise the creation of a geodatabase for the project that contains a domain with all substrate classes in the map classification scheme. The polygon shapefile can be loaded into this geodatabase and assigned the domain. When editing the polygon file, each polygon is selected and the proper substrate class is easily assigned via selection from a drop-down menu displayed in the attribute table of the polygon file. Each class can be symbolized with a unique color; as the classification process unfolds the map becomes a rich mosaic of patches.

- **Merge substrate and bank polylines, convert areas bound by lines to polygons**
- **Create geodatabase with domain that includes all substrate classes- load polygon file**
- **Assign class to each polygon**
- **Examine map at several scales to assist with interpretation**

Create and Classify Polygons

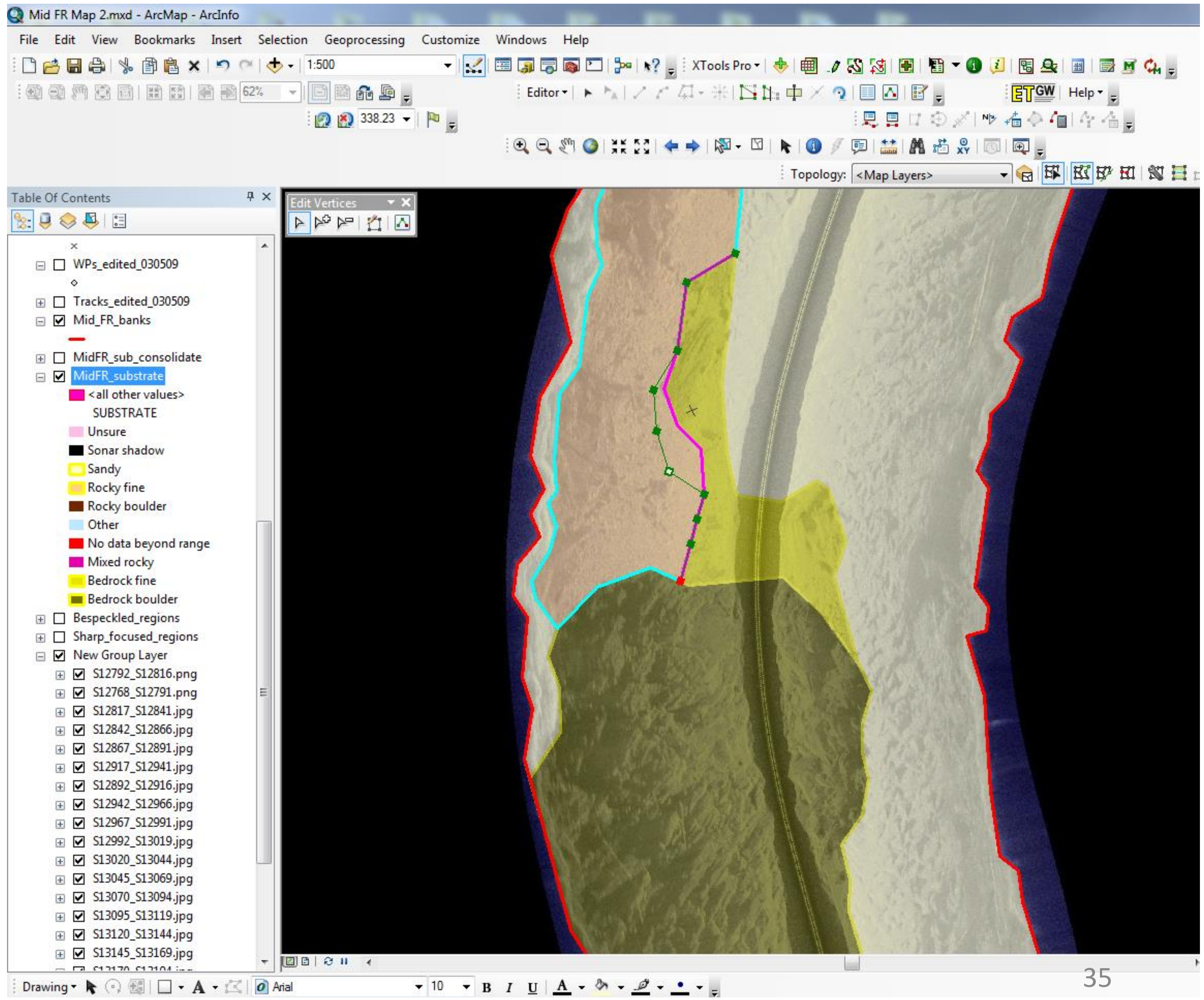


Flexibility during editing

There exists a tremendous amount of flexibility during this stage of the mapping process. In practice we proceed with assigning classes to the entire set of map polygons, then remove all color symbolization and instead display coded values representing each substrate class within the polygons during a review and editing session. We inspect the entire map, top to bottom, for consistency in boundary digitization and classification. During this review process, a variety of editing tasks can be undertaken: polygons can be split (using Task- Cut Polygon Features), manipulated (redrawn) using Map Topology (Topology edit tool), merged (under Edit- Merge) with adjacent polygons, or reclassifed wherever necessary. In this example we are simulating the adjustment of the boundary line separating rocky fine (tan) from bedrock fine (light olive) class polygons, using the Topology edit tool.

Map makers should familiarize themselves with the suite of tools available for editing, in addition to the topic of Map Topology- the ArcGIS Help menu is a good place to start.

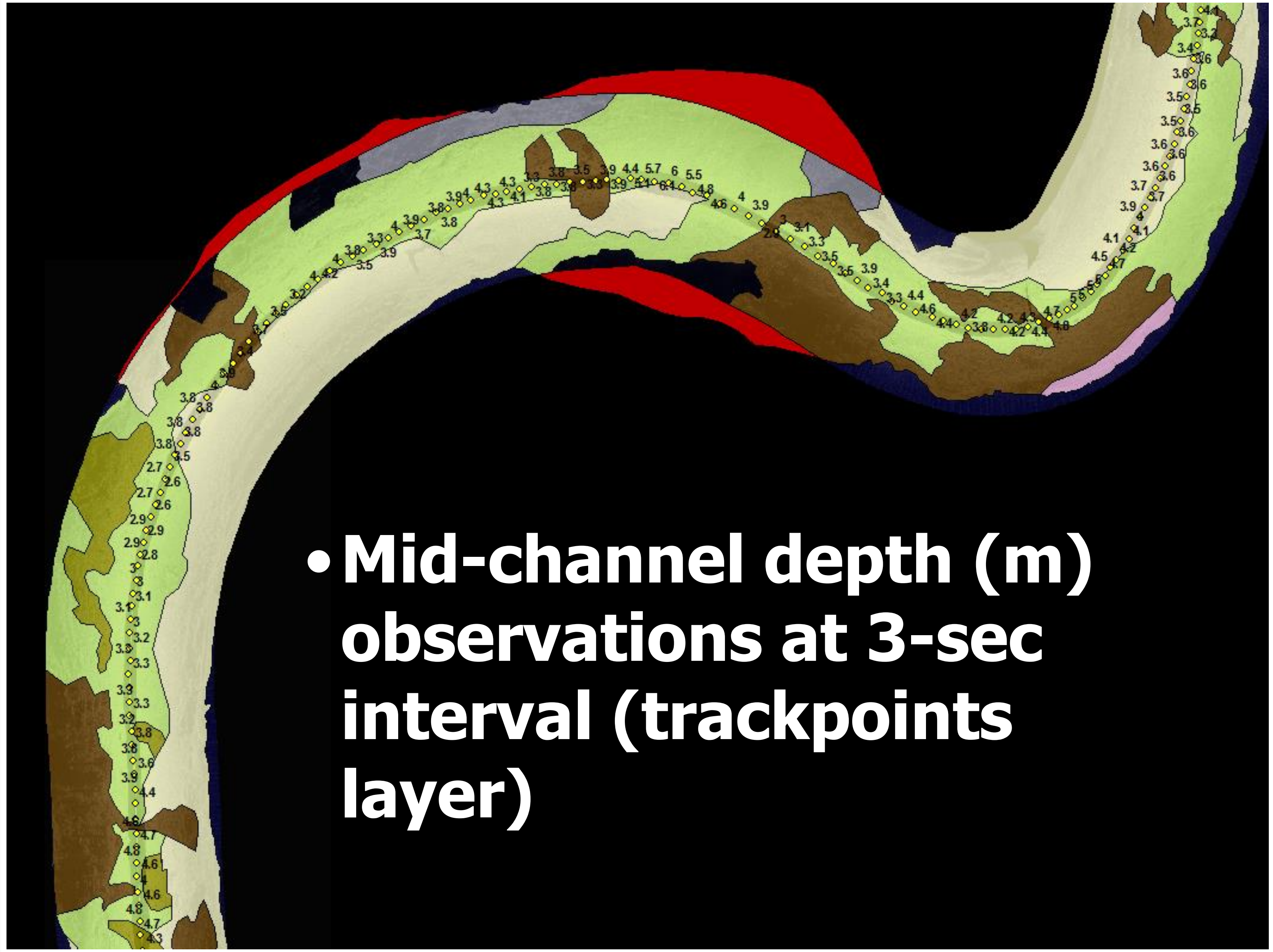
Editing Polygon Shapefile



Working with depth data

When making a single pass survey we capture a detailed data set on depths directly beneath the boat. Although these data are limited, mid-channel observations (as shown here) typically provide useful information on general bathymetric trends for the system.

Depth data



- **Mid-channel depth (m) observations at 3-sec interval (trackpoints layer)**

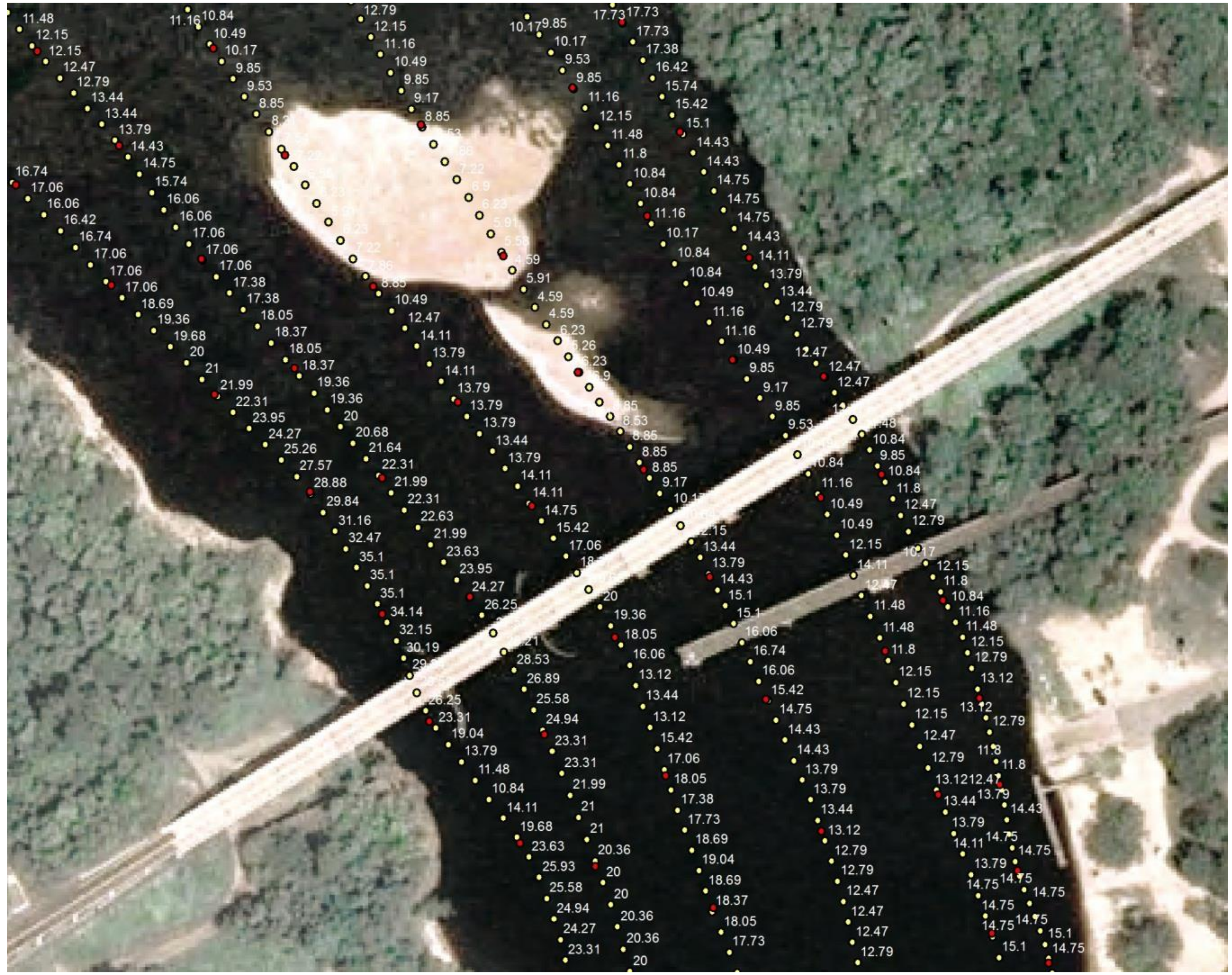
Multiple passes

When multiple passes are conducted across a water body, the data can be used to derive a more complex bathymetric model relevant to the water surface elevation experienced during the survey. Additional data would be needed to calibrate depth observations to a standard elevation such as mean sea level.

In this example 6 passes were made across this channel. Two additional lines of data are available after defining the bank lines from the sonar imagery (i.e., the channel margin at 0 water depth). This fairly robust data set could be used to produce a nice bathymetric model using tools available in ArcGIS at the ArcEditor or ArcInfo level.

The extension 3D Analyst (ArcEditor or ArcInfo level license) can be used to derive terrains, e.g., a bathymetric map

Mapping Bathymetry



A 3-pass model

Here is an example of a crude bathymetric model produced using data from only 3 sonar passes, plus a layer defining the banks of the river. At first glance, the model appears to represent the shallow sandbars well, and identifies several of the deeper portions. Such models may be crude (to an engineer), yet useful for purposes of studying habitat at the reach or system scale.

Coarse Bathymetry Layer - TIN

Basic summary

When the substrate map is complete and finalized, we can summarize and present the data in a variety of ways. Simple statistics like length and area mapped, and average width and depth can be generated using ArcGIS tools. Here we have represented the total coverage of each substrate class in the study area in a pie chart. This chart provides easy visualization of substrate composition in the study area. Approximately half of the channel was covered by sandy substrate, and the other half by a variety of rocky substrates. A combined total of 7% of the mapped area was classified as unsure/uncertain.

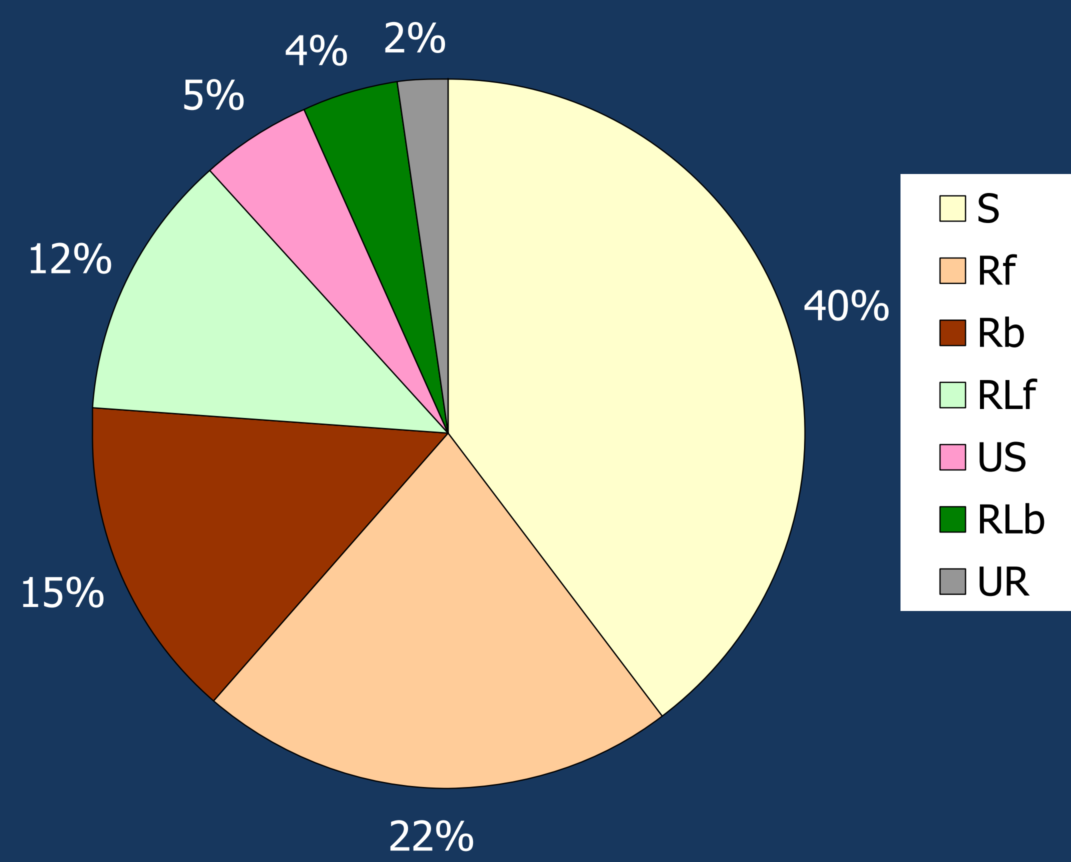
Summarizing Map Data

Ichawaynochaway Creek

Length of Creek Mapped= 26.75 km

Area= 101.1 hectares

Mean Width= ~38 meters



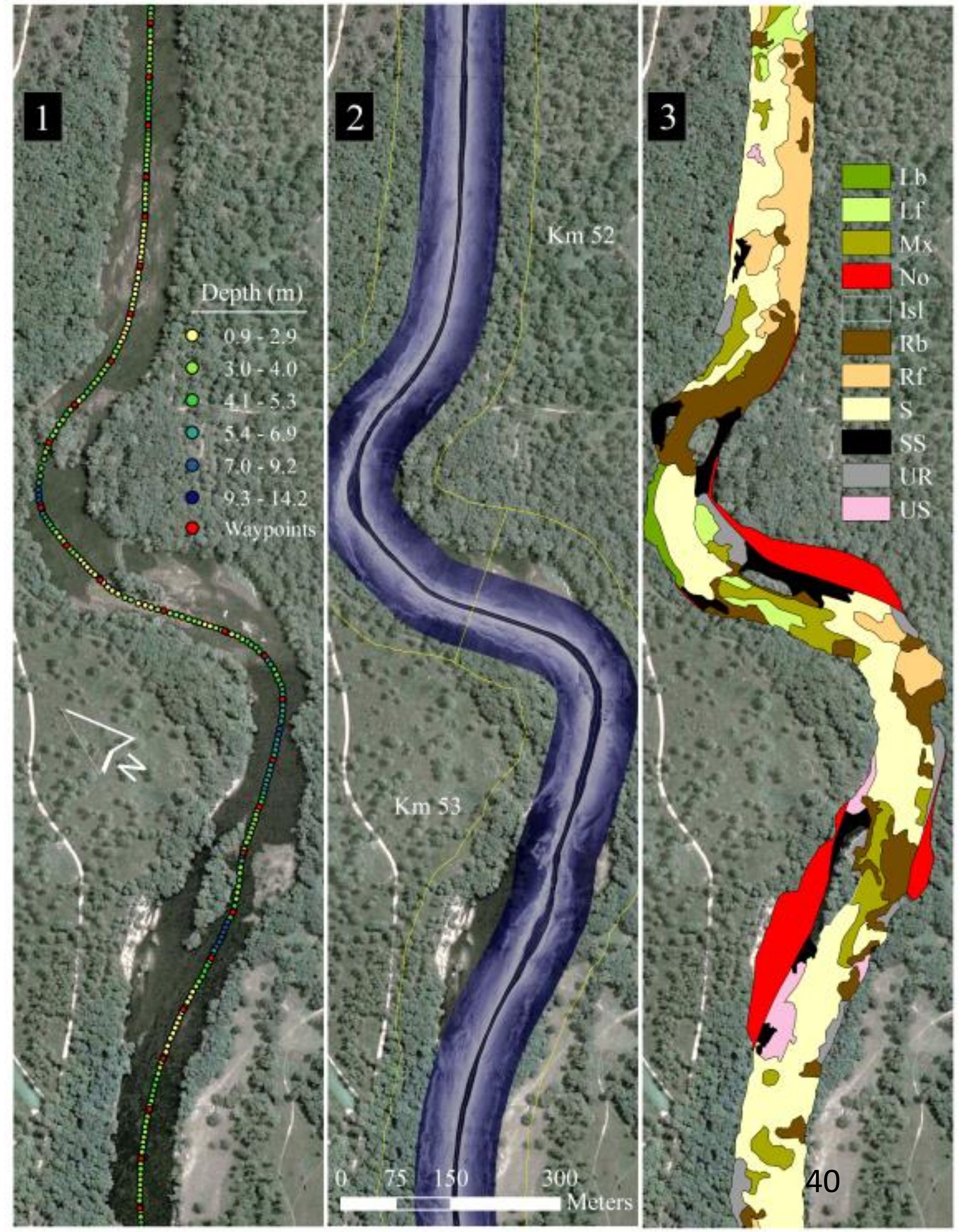
Longitudinal trends

A slightly more sophisticated approach to summarizing map data that reveals longitudinal trends involves extracting data from fixed reaches. In this example we created a polygon shapefile that overlaid the river channel and subset the polygon into 1-km blocks. (Although difficult to see in the image on the right, the outline of this polygon file is displayed in yellow in panel 2). This shapefile was used to clip and summarize data within each 1-km reach of the river map.

Summarizing Map Data

Another approach

- **Divide river into reaches (eg. 1km)**
- **Extract and summarize data by reach**



Longitudinal trends

The resulting illustration of longitudinal trends in substrate composition and depth is striking. This figure displays the substrate composition of each 1-km reach of river from Albany, GA (river km 121) to Bainbridge, GA (river km 0). Several marked trends are revealed by this figure. From Albany to Bainbridge the substrate composition changes from one dominated by limestone bedrock (Lf) to sand (S). The explanation for this trend is the fact that a dam sits just above river km 121 on the Flint River. This dam effectively blocks sediment delivery to the upper river, and over time scouring and downstream transport of sand have exposed the underlying limestone bedrock of the region. Other information is revealed, such as reaches of river that exhibit a high proportion of rocky shoal (Rb) habitat. We also find that the proportion of unsure and missing data (US/UR/SS/No) generally increased in the downstream direction, a result attributable to the use of higher range settings to accommodate for changes in river width during the single-pass survey. This figure and trends are discussed in greater detail in Kaeser et al. (2012).

In this chapter we've discussed the map classification scheme, the digitization of bank and substrate boundaries, polygon classification and editing, working with depth data, and summarizing map data. In the final chapter of this workbook we turn our attention to woody debris as a case study on feature identification and index development, and assessing the elements of map accuracy.

Trends in Substrate Composition and Depth