

Session IV- Part B

Let's turn our attention to the topic of mapping large woody debris with side scan sonar. Our earliest endeavors with the Humminbird SI system involved this element of habitat. Given the importance of wood to the ecology of streams of the Southeast Coastal Plain, we set out to determine if side scan sonar could be used to reliably quantify and map large woody debris in the turbid, nonwadeable streams of the region. The timing couldn't have been better for us in that 2007 proved to be year of epic drought that led to low and clear water conditions in our study streams. Much of the groundtruth work was conducted by swimming, snorkeling, and diving- the perfect prescription for field work during a South Georgia summer.

Large woody debris has been variously defined in the literature; we used a common definition that specifies large woody debris (LWD) as any piece of wood that is greater than, or equal to 10 cm in diameter over a length of 1.5 meters or more. I asked Josh, our habitat intern, to find a piece of wood that just qualified as LWD. The log he is holding is exactly 10 cm diameter, and is about 2 meters long (the red line represents 1.5 meters). When we talk of mapping LWD we are talking about pieces of wood this size or larger.

Mapping Large Woody Debris

a piece of wood $\geq 10\text{cm}$ diameter & $\geq 1.5\text{ m}$ long

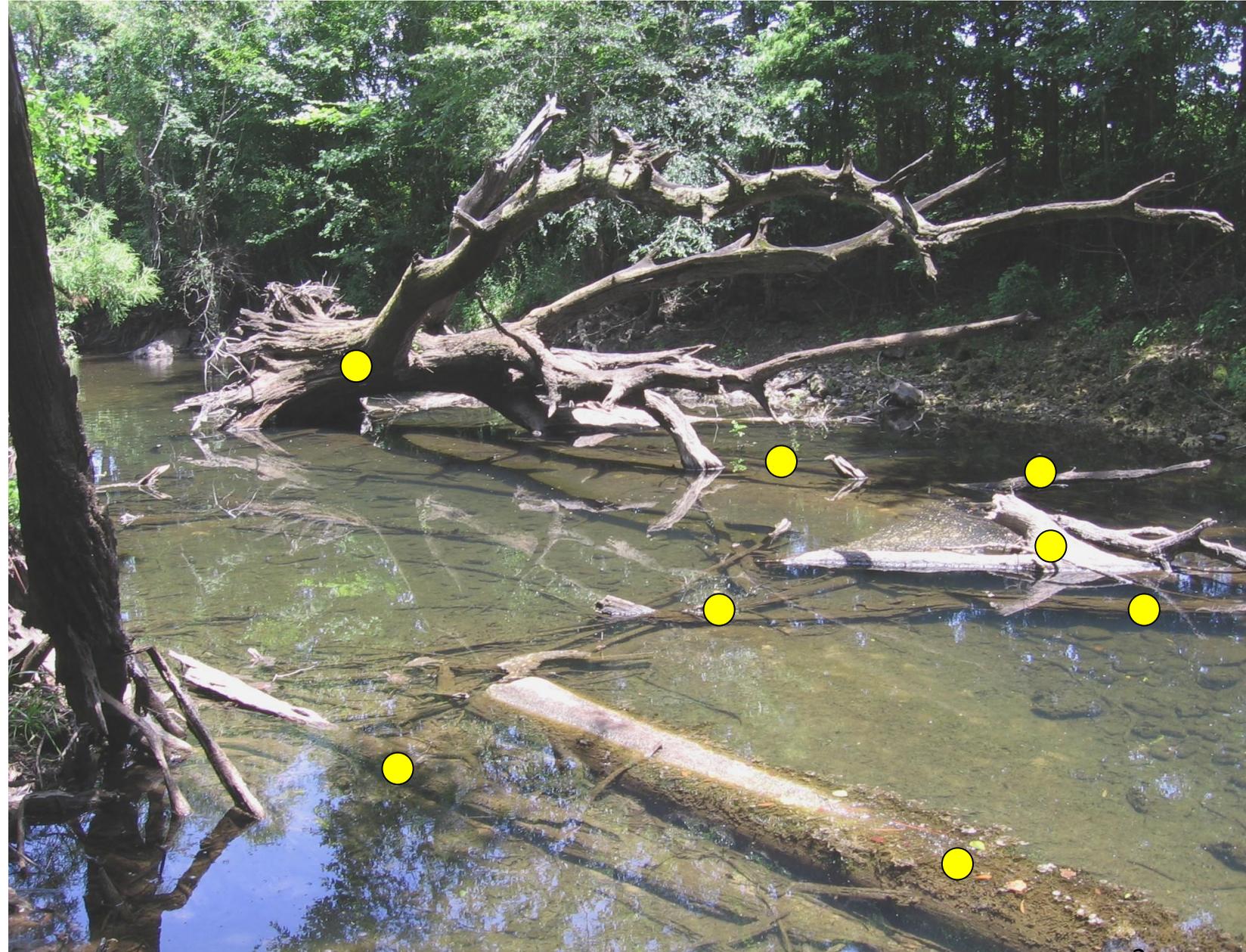


LWD as case study

LWD comes in a variety of shapes, sizes, and forms. We sometimes find accumulations of LWD, as seen here, that include whole trees, deadhead logs, and various other pieces. The goal of our wood studies was to determine if these habitat elements could be discriminated from other features appearing in sonar imagery, and whether counts and mapped locations of individual pieces of LWD in sonar imagery were accurate and/or precise with respect to the actual amount of LWD present in the stream.

We are going to spend some time discussing this work- not to give undue attention to woody debris- but to present the topic as a case study that provides insights that may be relevant to a variety of physical elements of interest in aquatic systems. As we proceed, consider the possibility of substituting an alternative object or feature of interest (e.g., large-bodied fish, fish beds, crab traps, tires, etc.) for large woody debris in the discussion.

A variety of LWD



Levels of effort

At least three options exist for mapping and/or quantifying submerged LWD. If sonar counts of LWD within defined reaches of a stream are all that is desired, mosaics of raw sonar imagery can be prepared and counts can be made of the visible pieces of LWD (Option 1). In this approach, LWD is identified from the original, raw sonar imagery. Option 2 involves fully processing the sonar imagery to create sonar image maps (SIMs), inspecting the SIMs, and digitizing all apparent LWD as points on the map. In this approach, LWD is identified from the processed, rectified sonar imagery. One major advantage of this approach is that each piece of LWD is assigned specific geographic coordinates- information that might be useful to the study.

Option 3 represents a hybrid approach, where LWD is digitized as point features on the raw sonar imagery, the points are “burned” into the image, and the images are then processed and rectified- thereby putting the points into real geographic space. We have not tested Option 3, so it remains only theoretical at this point.

Options for LWD Mapping

Option 1. Generate mosaics using raw sonar images, load in GIS, digitize as point features

If only relative abundance of LWD is important this option eliminates geoprocessing effort

Option 2. Digitize LWD on rectified SIMs

Advantage- puts LWD into real geographic space

Option 3. Digitize LWD on raw mosaics, “burn” point features into image, then rectify

Option 1 details

Following Option 1 we batch crop the raw sonar images from the study area, then use the image matching tool in Thom's Sonar Toolkit to clip images at overlap points. The Create Panorama Image function in IrfanView is then used to prepare large, seamless mosaics of the clipped, raw (unrectified) imagery. The mosaics are loaded and viewed in ArcGIS (or viewed in any other image viewing program) to derive counts of apparent LWD.

- 1) Batch crop raw images using Irfanview (crop settings file provided)
- 2) Use Image Matching Tool to clip images at overlap point
- 3) Use Irfanview to generate mosaics from clipped images

Option 1. Digitize LWD in Raw Image Mosaics (using Irfanview and ArcGIS)

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Consider this cache

Here is a nice cache of deadhead logs, exposed during the extreme drought conditions of 2007 in Southwest Georgia.

Chickasawhatchee Creek Log Cache

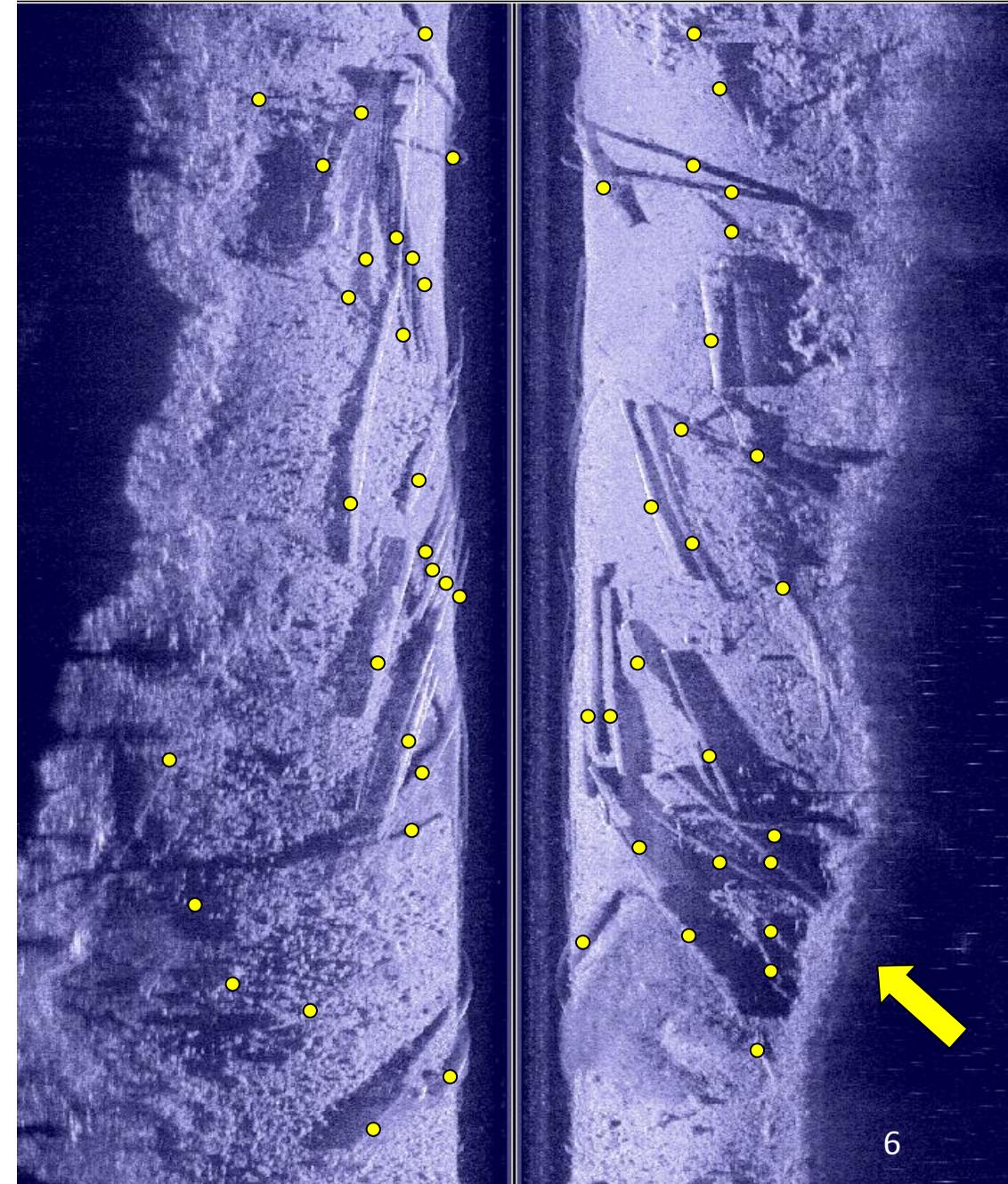


Counts from raw mosaic

This is the corresponding raw image mosaic prepared for the Chickasawhatchee Creek log cache. The yellow arrow identifies the location from which the photograph was taken for purposes of referencing individual logs seen in the sonar imagery to the logs in the cache photograph. This mosaic, when loaded in ArcGIS as a raster file, can be inspected to assign points to each piece of LWD as shown here. When done, a polygon can be created to bound the study area and used as a feature to clip and tally the number of pieces of LWD.

Option 1 for LWD Mapping

- **Load reach mosaic in GIS**
- **Create point shapefile for reach**
- **Digitize LWD identified in reach mosaic**

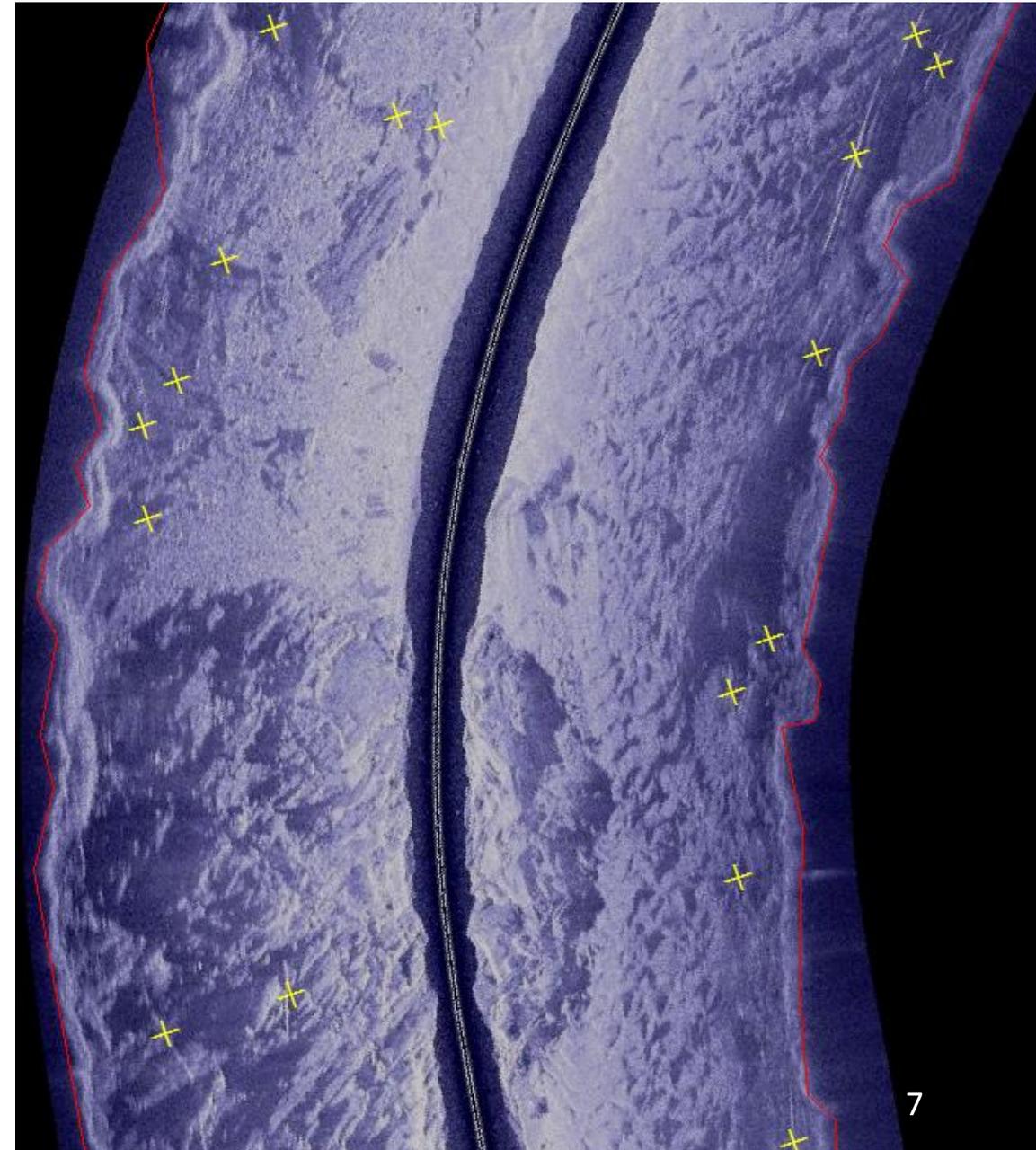


Counts from SIMs

Option 2 for LWD mapping is similar in approach, except that the imagery is rectified, and the sonar image map layers are used to identify and map actual locations of the LWD. In this example we used a point shapefile symbolized as a yellow X to identify pieces of LWD.

Option 2 for LWD Mapping

- **Create point shapefile for LWD**
- **Digitize LWD identified in SIMs**
- **Can extract LWD counts by clipping features from portions of the map and summarizing**



Evaluating sonar counts

Anyone can put points on a map and count wood in a sonar image. The important question to address was whether sonar counts were accurate and/or precise with respect to the actual amount of LWD present in stream reaches. To answer this question we needed to return to study reaches and manually measure and enumerate all of the LWD. This is no small feat in reaches with a lot of wood. Fortunately, large wood doesn't appear to move around much in the low gradient, low power streams of the region, especially during a drought year such as experienced during the study.

Assessing Sonar Wood Count Accuracy and Precision



**Ground-truth
Wood Survey**

- LWD enumerated in the field

Inaccurate yet precise

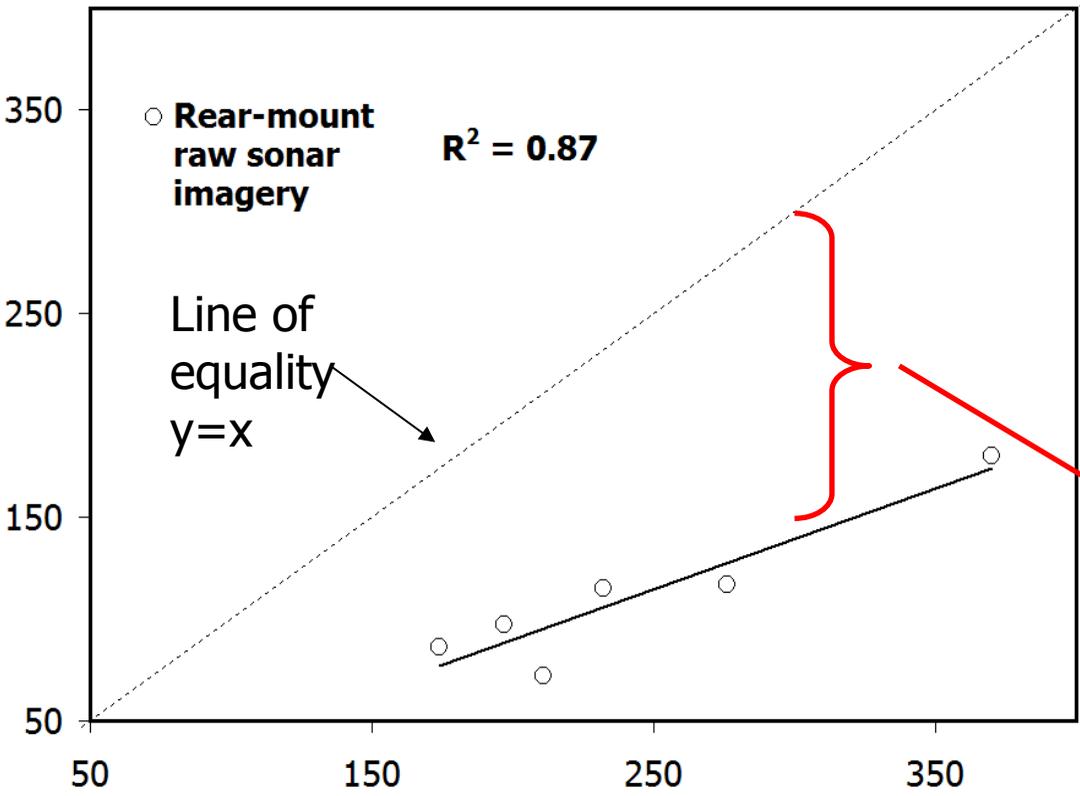
The groundtruth surveys provided counts of actual LWD to compare to sonar LWD counts made by a single image interpreter. In the next three slides we present data from one of the study streams, Ichawaynochaway Creek. This stream was surveyed twice during the spring of 2007. In this example we are presenting sonar counts made from imagery produced with a rear-mounted sonar transducer set at a range of 85 feet per side. Six reaches, each 500-700 meters long, were surveyed during the groundtruth operation. If sonar counts were 100% accurate (i.e., all of the actual LWD present in the stream reach was visible and counted in sonar imagery), then the data points in this figure should line up along the line of equality $y=x$ (dotted line). The points do not fall along this line, rather the sonar counts of LWD are quite a bit lower than the actual abundance of LWD in the reaches. The gap between the line of equality and the line fitted through the data points represents the amount of LWD not visible in this sonar image data set. This result should come as no surprise in light of our earlier discussion of the performance of the rear-mounted transducer.

On the other hand, the sonar counts are highly correlated with actual LWD abundance, and there's something to be said for that.

Sonar vs Actual LWD Counts

Ichawaynochaway Creek, range= 85 feet per

Sonar Estimated LWD



6 reaches each 500-700m long

Some LWD not visible in sonar imagery

Actual LWD Counts

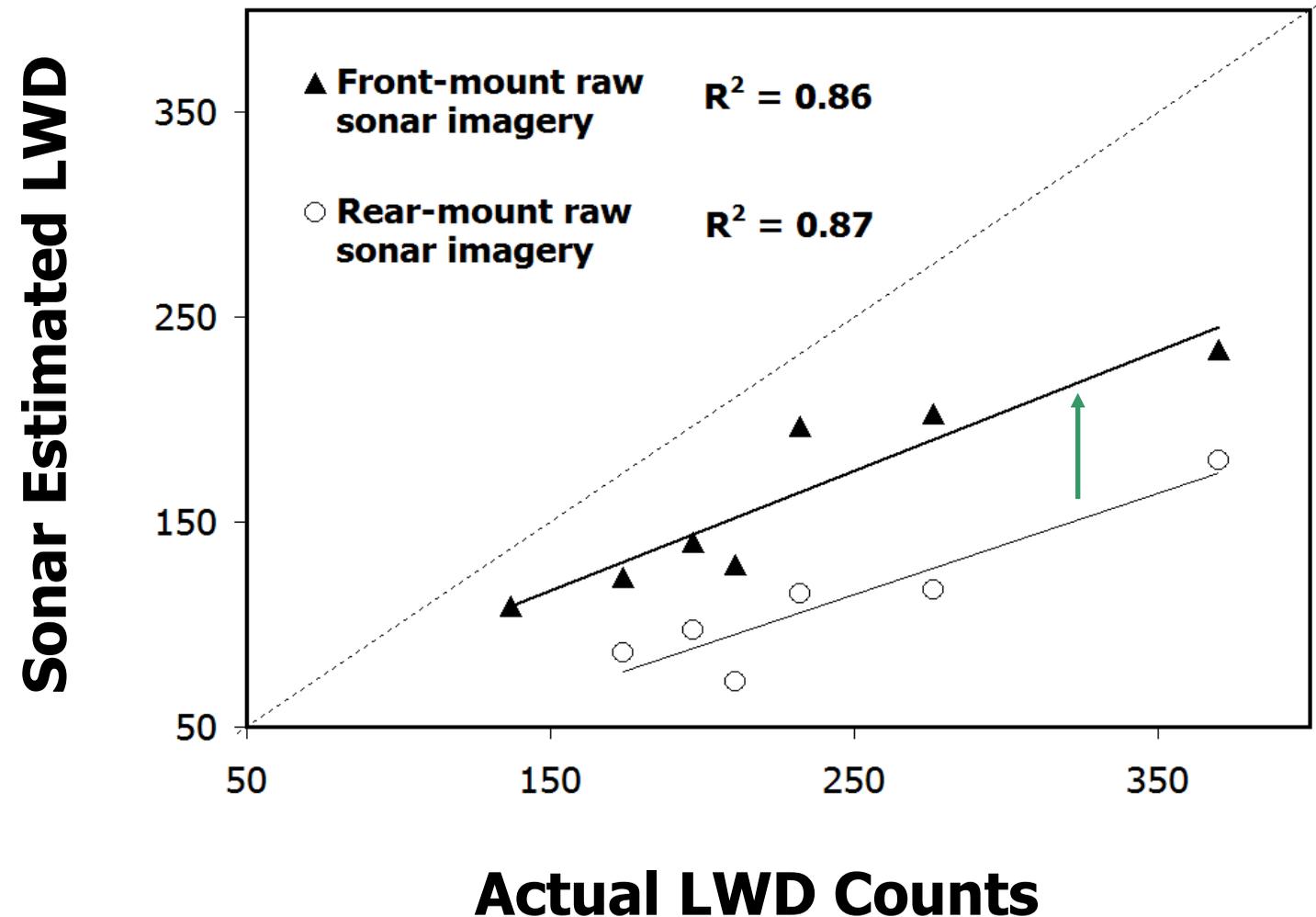
Effects of transducer

In this figure we have added the sonar count data generated from imagery created with a front-mounted transducer. Counts made from front-mounted imagery were more accurate- more of the LWD present in the stream reach was visible. This result is consistent with our observations of enhanced image quality when using a front-mounted transducer. Sonar counts still fall below the line of equality, thus we still cannot identify all of the LWD in sonar imagery that was actually present in the study reaches. Nonetheless, the correlation between sonar counts made with the front-mount transducer and actual LWD is high and identical to that of the rear-mount transducer. High correlation values indicate that sonar counts are precise. In addition to the consistent performance of the Humminbird system, we attribute high precision of sonar counts to the ability of the sonar interpreter to maintain consistency throughout the review process. With high precision, the sonar count data set could be used to provide a reliable index of relative abundance of LWD in the reaches. Alternatively, linear regression could be used to calibrate sonar counts to actual abundance of LWD in reaches that were not groundtruthed.

- **Front-mount reveals more LWD**
- **Sonar counts are precise- provide index to LWD**
- **Linear regression to calibrate sonar counts to actual LWD**

Sonar vs Actual LWD Counts

Ichawaynochaway Creek, range= 85 feet per side



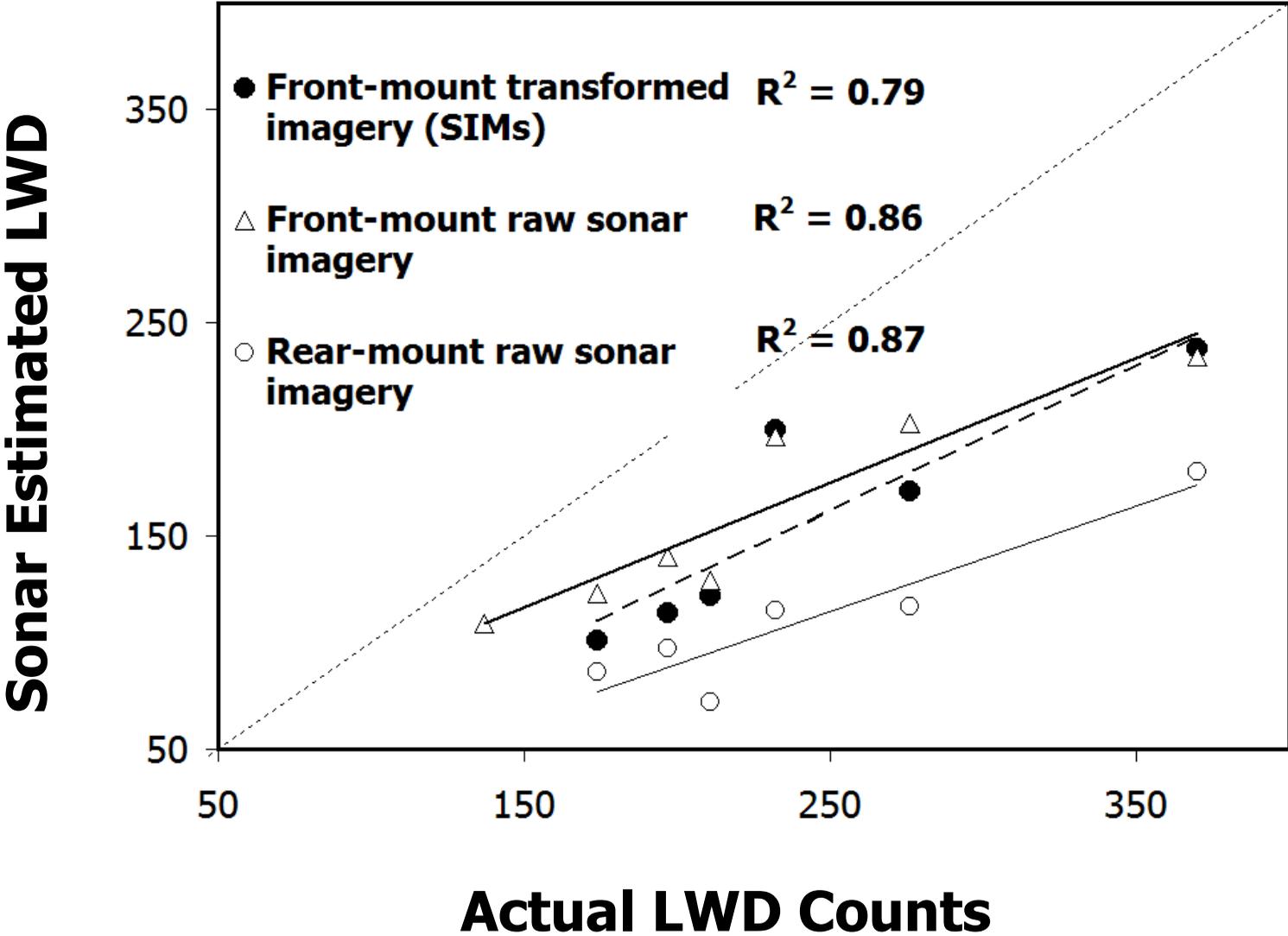
Effects of rectification

Lastly, we add a data set representing sonar counts of LWD made from the front-mounted, rectified imagery. The results indicate that rectification, in this case, had little effect on the accuracy or precision of counts of LWD.

- Rectification did not greatly effect LWD observed in sonar imagery produced with a range of 85 feet per side

Sonar vs Actual LWD Counts

Ichawaynochaway Creek, range= 85 feet per side



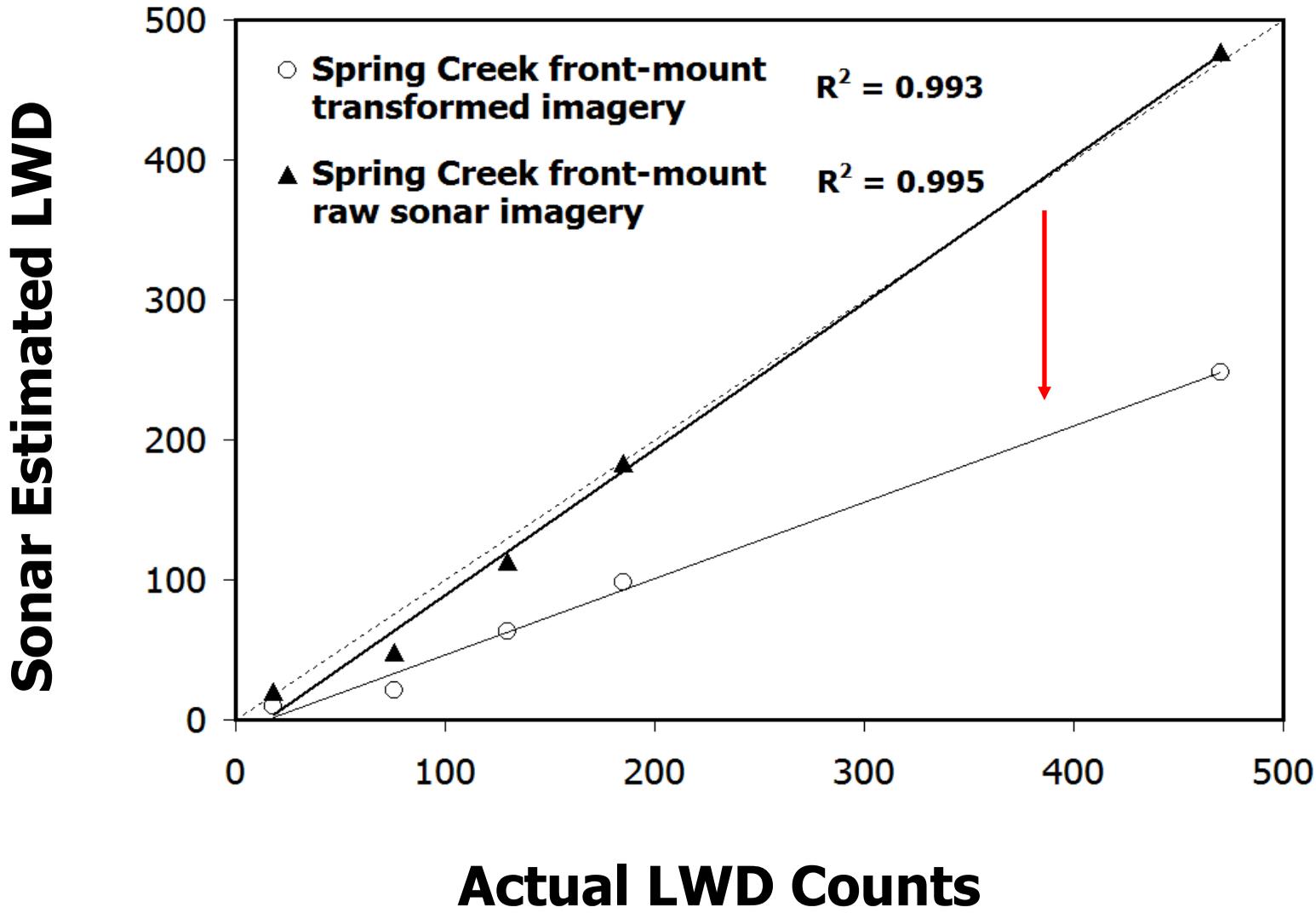
Different stream

Here we present a data set that did not appear in Kaeser and Litts (2008). These data come from surveys conducted in Spring Creek, a smaller stream in an adjacent watershed. When conducting the sonar survey for this work, a lower range setting of 65 feet per side was used to capture full channel imagery. This figure illustrates the relationship between counts made with front-mounted, raw sonar imagery and actual LWD counts (black triangles), and the relationship between front-mounted, rectified imagery and actual counts (open circles). The results are quite interesting indeed! In this case, it appears that all or most of the actual LWD was identified in the front-mounted, raw image data set; accuracy and precision of sonar counts were exceptionally high. We attribute the improved accuracy of counts to the use of a lower range setting. Lower range settings improve image resolution, bringing smaller objects (i.e., smaller LWD) into focus. Do these results indicate that 65 feet per side is the ideal range for detection of LWD? Perhaps. More work is necessary before drawing this conclusion.

Unlike the Ichawaynochaway Creek case, however, rectification of sonar imagery from Spring Creek led to lower sonar counts (i.e., decreased accuracy). We believe the process of rectification decreased our ability to resolve the smaller pieces of LWD. Nevertheless, the counts made from rectified imagery were precise, and could also serve as a reliable index of relative abundance of LWD in this study area.

Sonar vs Actual LWD Counts

Spring Creek, range= 65 feet per side



Food for thought

During our studies of wood we began learning about the performance of the system and the work required to develop and evaluate sonar habitat mapping applications. We learned, through first-hand experience, that some objects simply imaged better than others due to a variety of factors such as orientation, position in the stream channel, size, and density. We learned that the sonar range setting affected our ability to resolve objects. Image processing also had the potential to affect object resolution, yet the effects were variable and appeared to be influenced by factors such as range and the general size of the objects.

These lessons provide a lot of food for thought when working to develop and evaluate side scan sonar mapping applications. What ranges should be used when targeting an object- should imagery be rectified or is the raw format best?

Lessons Learned

- **Some objects image better than others due to orientation, context, size, and density**
- **As range decreases, more LWD (smaller pieces/objects) can be discerned**
- **Rectification can affect object definition and recognition, but the effects appear variable (driven by other factors, like range used)**

Pursue applications

Our work with wood and low-cost, side scan sonar is featured in a 2008 Fisheries article. This article contains additional recommendations, such as the use of non-randomly selected reaches during the development of a system-specific index of woody debris abundance.

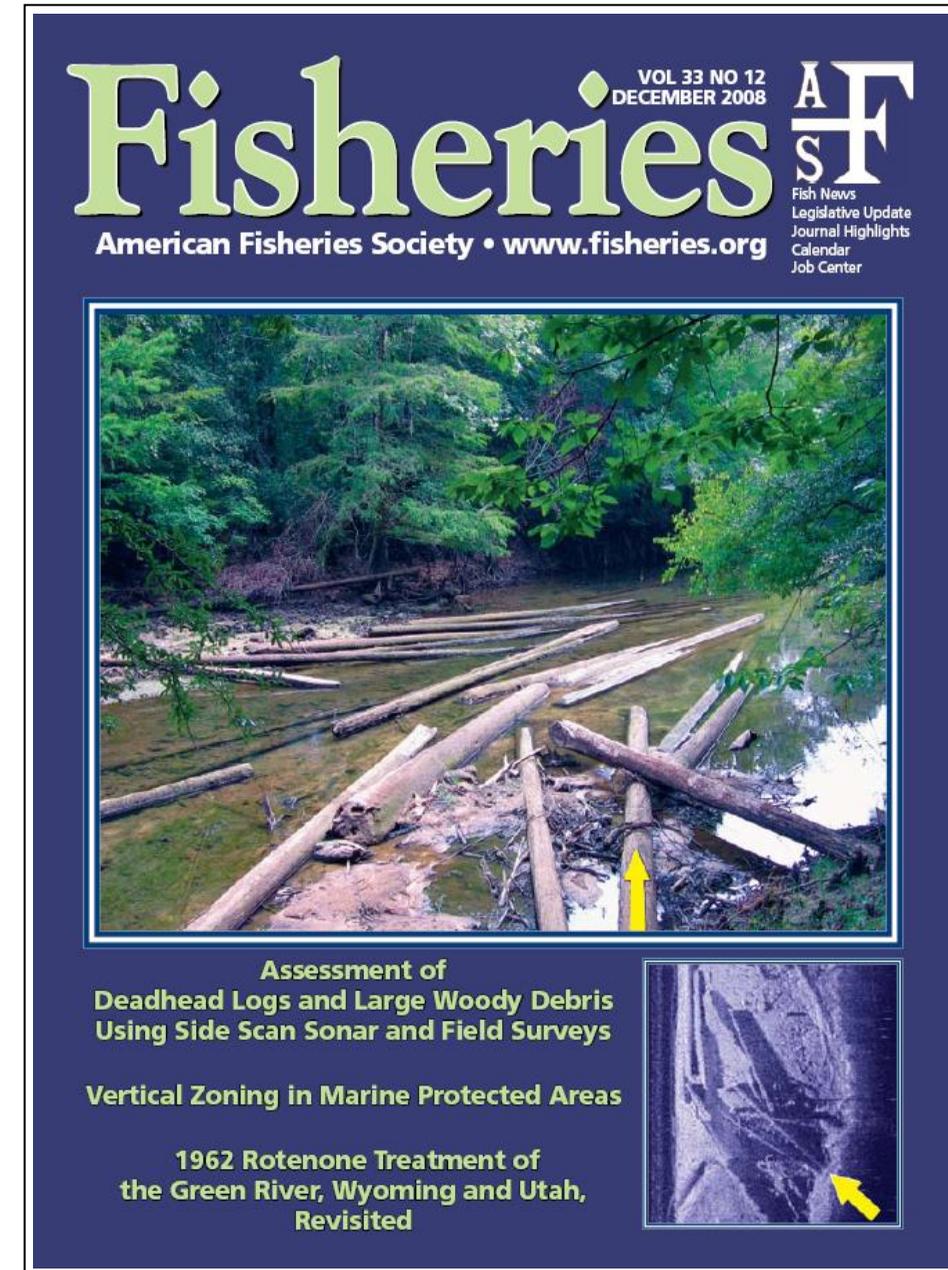
The intent of this article was two-fold- to draw attention to a resource that is imperiled and understudied, yet common to the region (i.e., deadhead logs), and to introduce the concept of assessing wood at the landscape scale using a low-cost, remote sensing tool. We would be pleased if this case study helps to stimulate additional work to develop and evaluate applications of low-cost sonar habitat mapping.

Let's step away from woody debris, and revisit the 5-step process of developing a sonar-based habitat map to see how far we have come.

Other Recommendations

E.g., Calibrating Wood Counts

Non-randomly select reaches (eg. 100 m) that represent full range of wood abundance (low to high, from sonar counts) for field counts during low flow conditions



Developing a habitat map

Step A-
Conduct the
sonar survey



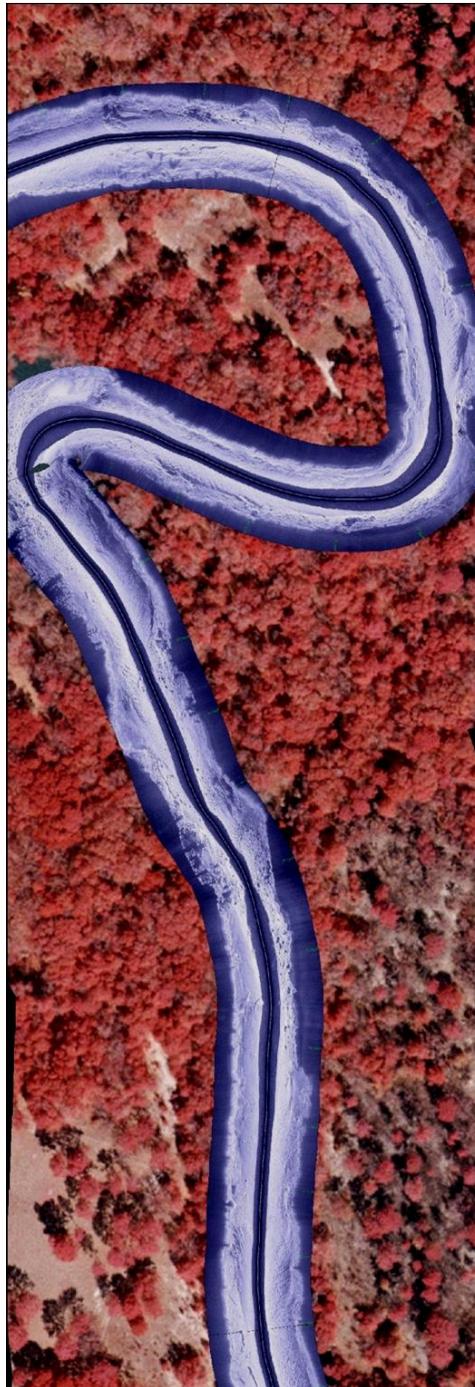
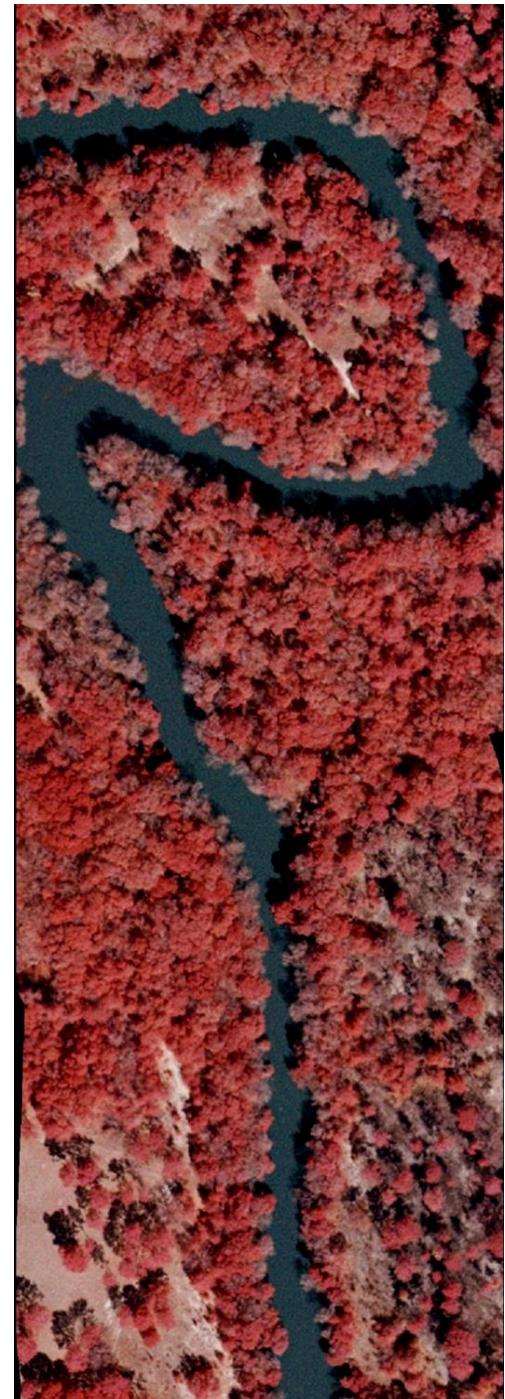
Step B-
Geoprocess
sonar data to
create a
sonar image
map layer

Reviewing the 5-Step Process

Step C-
Develop a
classification
scheme



Step D-
Delineate
bank and
substrate
boundaries in
GIS at
appropriate
scale



Developing a habitat map

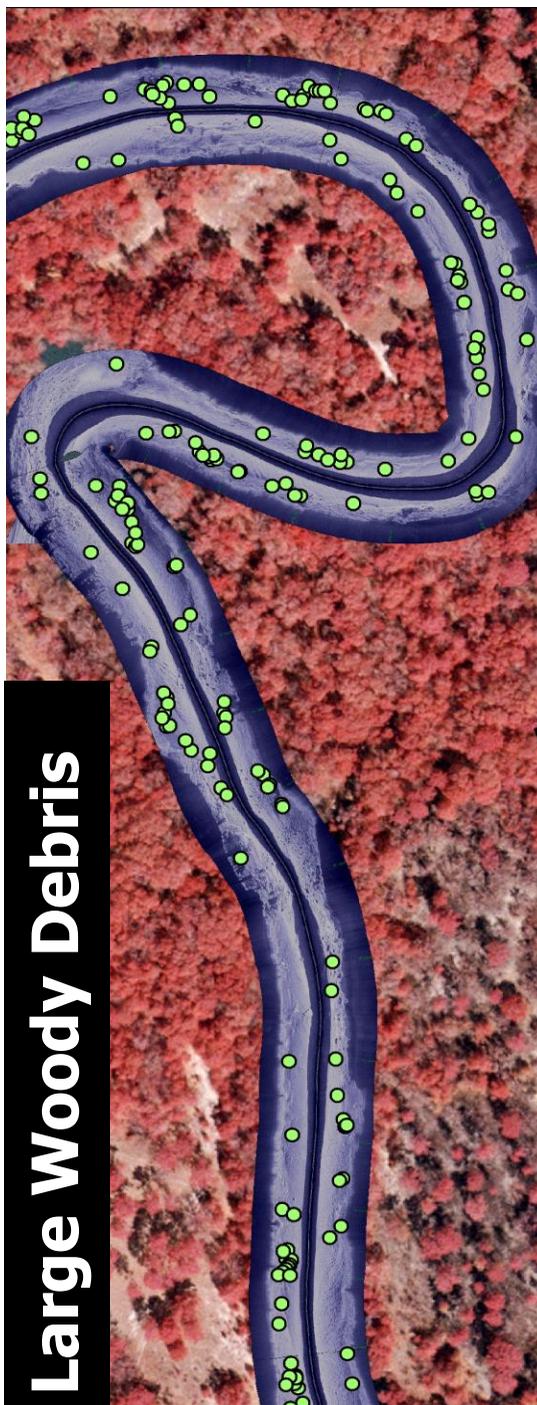
Step D cont.- Classify substrate polygons

- Rocky boulder
- Rocky fine
- Rocky limerock boulder
- Rocky limerock fine
- Sandy
- Unknown presumed rocky
- Unknown presumed sandy

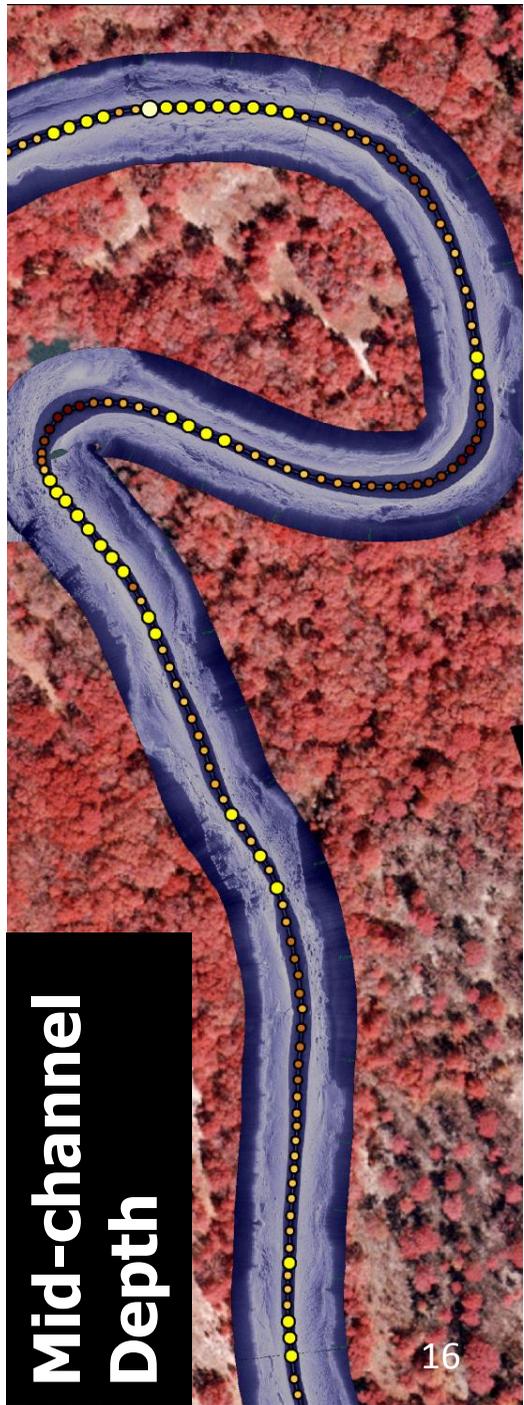
Reviewing the 5-Step Process

Step D cont.- Digitize LWD, other features

Display depth data or produce bathymetric model



Large Woody Debris



Mid-channel Depth

Step E- Map accuracy

A final, yet very important step in the process of developing a habitat map is the assessment of map accuracy. It's way too easy to assume that your map is correct once it's staring back at you on the computer screen. Your map- like any model- is merely an abstraction of reality. Like any good statistical or theoretical model, the map (and hence the map maker's skills) must be put to the test and validated.

There are three principle elements of map accuracy that are relevant to sonar-based habitat maps. The first element is dimensional accuracy. Dimensional accuracy relates to the size and shape of features that appear in the rectified sonar image map layers. Is it safe to assume that the sonar image maps are dimensionally correct? The second element is positional accuracy. An assessment of positional accuracy involves determining how much error is associated with locating map features in the field. A map object may be dimensionally correct, yet in the wrong, real-world location. The third element is classification accuracy. An assessment of classification accuracy involves determining whether features in the map were correctly classified.

A fantastic reference book on the topic of map accuracy assessment can be found in Congalton and Green (1999). This book was recommended to help guide our work during this critical step of the mapping process.

Assessing Map Accuracy

- 1) Dimensional Accuracy-** are rectified images dimensionally correct?
- 2) Positional Accuracy-** how much error is associated with locating map features in the field?
- 3) Classification Accuracy-** are substrate polygons classified correctly?

*Reference- Congalton, R.G., and K. Green. 1999. Assessing the accuracy of remotely sensed data: principles and practices. Lewis Publishers, New York.

Publications available

We have focused on evaluating all three elements of map accuracy, and evaluating the applications of mapping wood and substrates through a series of validation studies. These studies are published and available for supporting references and information. We have already discussed our first study at length (Kaeser and Litts 2008). We next focused on evaluating the ability to accurately characterize and map predominant substrates in a navigable creek (Kaeser and Litts 2010), and then scaled up the entire process of 1-pass sonar mapping to a medium sized river, covering over 100 km (Kaeser et al. 2012). This study also demonstrated that an undergraduate level technician could be trained to produce an accurate sonar-based habitat map. Our technician, Wes Tracy, turned the study into a senior thesis at the University of Georgia.

In this session we will discuss findings that relate to the three elements of map accuracy. These articles should be referenced for a more complete discussion.

3 Validation Map Studies

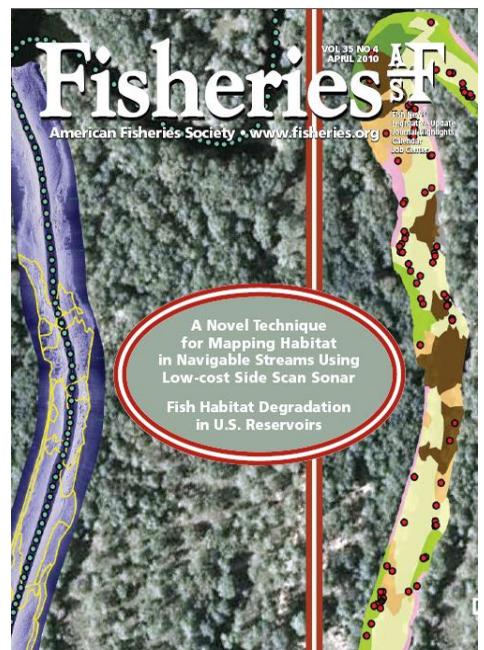
Sonar LWD Mapping

- South Georgia Creeks
- Actual LWD vs. Sonar Estimates
- Kaeser and Litts (2008)



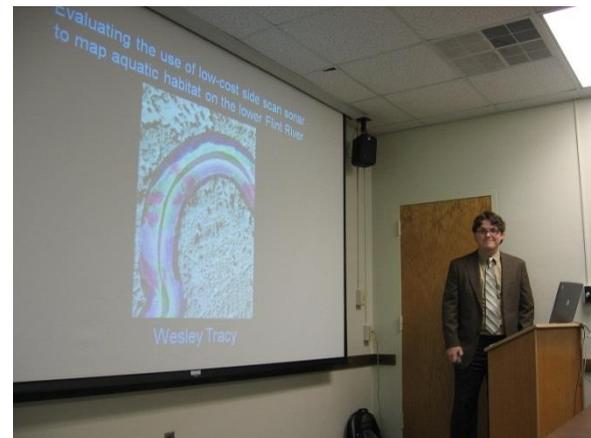
Sonar Substrate Mapping- Ich. Creek

- W 35 m, D 3.1 m, 27 km
- Overall Classification Accuracy= 77%
- Kaeser and Litts (2010)



Sonar Substrate Mapping- Flint River

- Intern produced map
- W 102 m, D 4.4 m, 124 km mapped
- Overall Class Acc= 84%
- Kaeser, Litts, and Tracy River Research and Applications (2012)



Timing is important

Before diving into the details of each element of map accuracy, let's consider the timing of sonar surveys relative to the necessary groundtruth work. The blue dots identify past high flow events targeted for sonar surveys, and the orange lines highlight periods of reference data collection. It is obvious that during the period 2006-2009 we targeted extended periods of low, clear water for gathering reference data. This timing was important, as it allowed us to measure several elements of habitat that would be difficult to assess during high, muddy water conditions. This doesn't mean that an evaluation of map accuracy can only occur during low, clear water conditions. Some creativity will be required when working in deep, turbid systems.

When mapping dynamic aquatic systems like rivers and streams, the timing of reference data collection relative to the sonar survey could be important. The goal when assessing classification accuracy, for example, is to determine if the map maker accurately classified map features. If these features have been altered by natural or anthropogenic phenomena, the ability to assess thematic accuracy will be confounded.

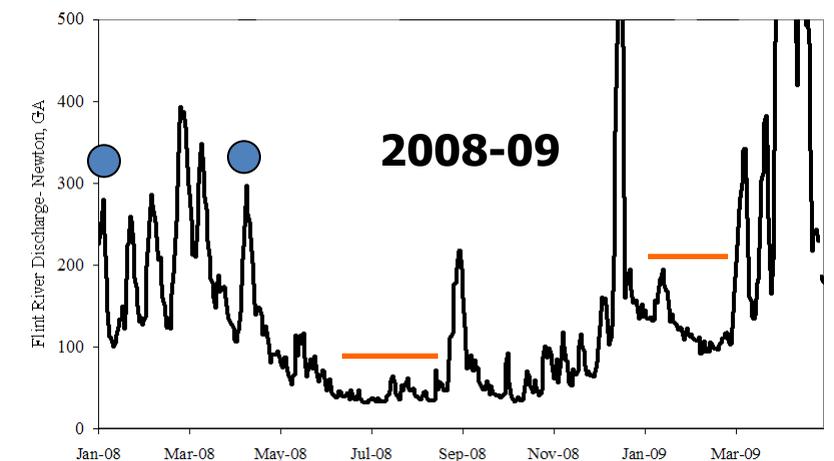
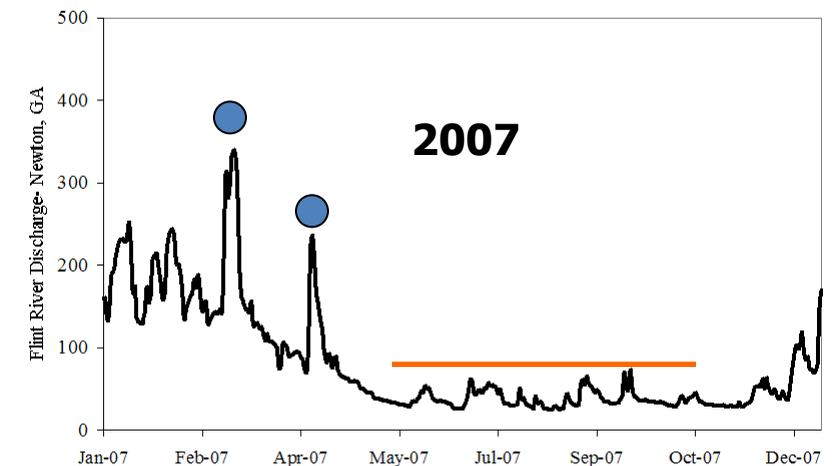
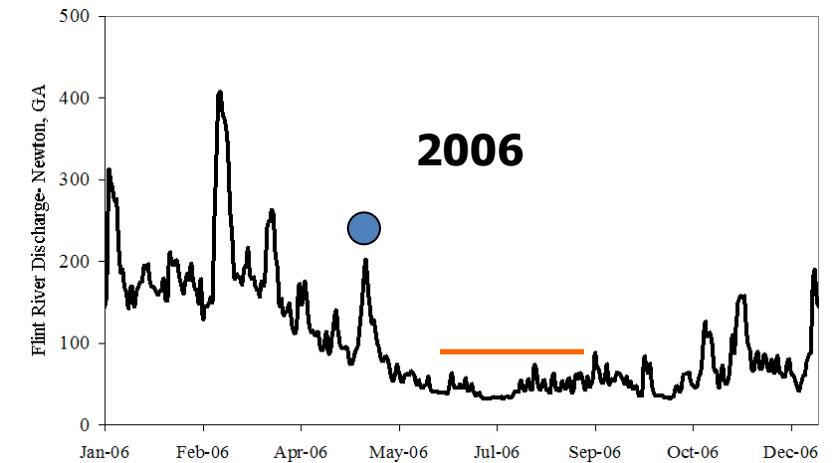
Planning Assessments



Sonar Surveys



Ground truth work



Benefits of a drought

When you need to visually assess substrate and count wood, conditions don't get much better than this! During the drought of 2007, upstream portions of this creek ran dry. Here, in the lower reaches, infiltrating ground water turned the stream into what looked like a blue hole spring run. It's hard to believe that during high flows this creek is among the most turbid in the region, with flow levels commonly reaching the top of the cut bank seen at the top and right of the photograph. Despite scorching summer temperatures, wetsuits were required to spend the whole day in the water collecting reference data. Here, Josh Hubbell floats over a large deadhead log. On the far side of the creek a limestone outcrop extends underwater to about mid-channel.

Spring Creek – Summer 2007



Sonar survey flows vs.

Ocmulgee River – Sonar survey

Here's a set of images to compare the difference between flows targeted for sonar survey work...



Reference data collection

...and the flows targeted for reference data collection. Note the level of the floating dock in this photograph relative to the level during the sonar survey. Although this stream is not crystal clear, the clarity was sufficient to permit visual inspection of substrate in the shallows, and the use of a drop camera in deeper areas.

Ocmulgee River – Groundtruth



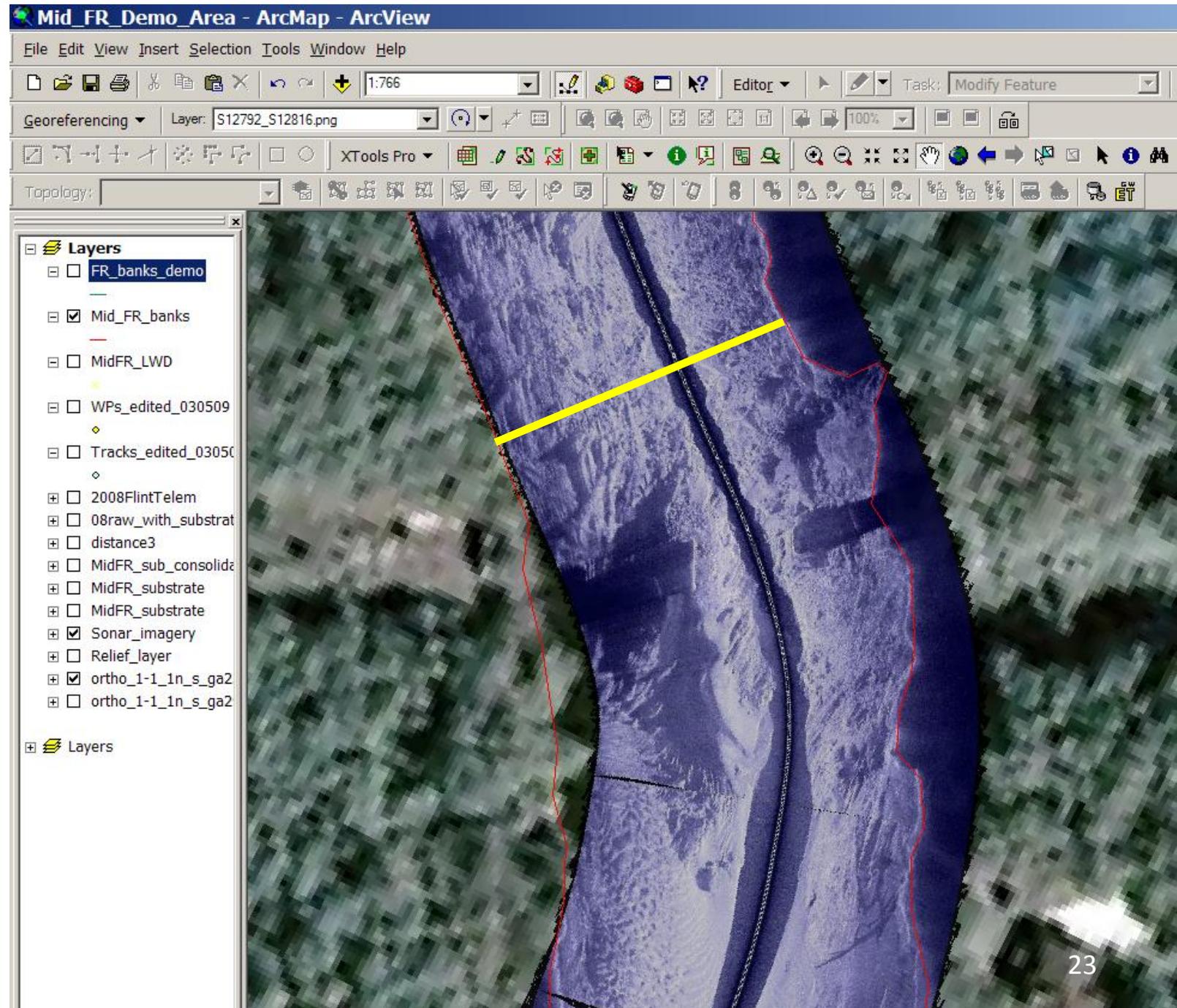
Do SIMs fit the channel?

Let's discuss dimensional accuracy first. A straightforward, qualitative means for assessing the dimensional accuracy of the sonar image map (SIM) layers is to overlay the transformed imagery on a reliable air photograph. If images have been geoprocessed correctly, and transformation has been successful, the SIMs should show exceptional fit to the stream channel. This evaluation can and should be undertaken in any mapping project involving image rectification.

In addition to visually assessing fit, we systematically measured elements from the SIMs using the ruler tool and compared these measurements to actual object dimensions obtained in the field. One of the elements measured was channel width, here illustrated as the yellow line drawn across the sonar image map.

- **Visual inspection- exceptional fit of sonar imagery to aerial images of stream channels**
- **Measured bankfull channel width in field to estimate reach area, compared to sonar estimates**

Dimensional Accuracy



Measuring width in field

When measuring channels in the field, we visually identified the bankfull elevation and used measuring tapes or rangefinders to measure width. In hindsight, a more accurate approach would have involved staking the water's edge during the sonar survey and returning to the stakes to measure channel width.

Bankfull Channel Width

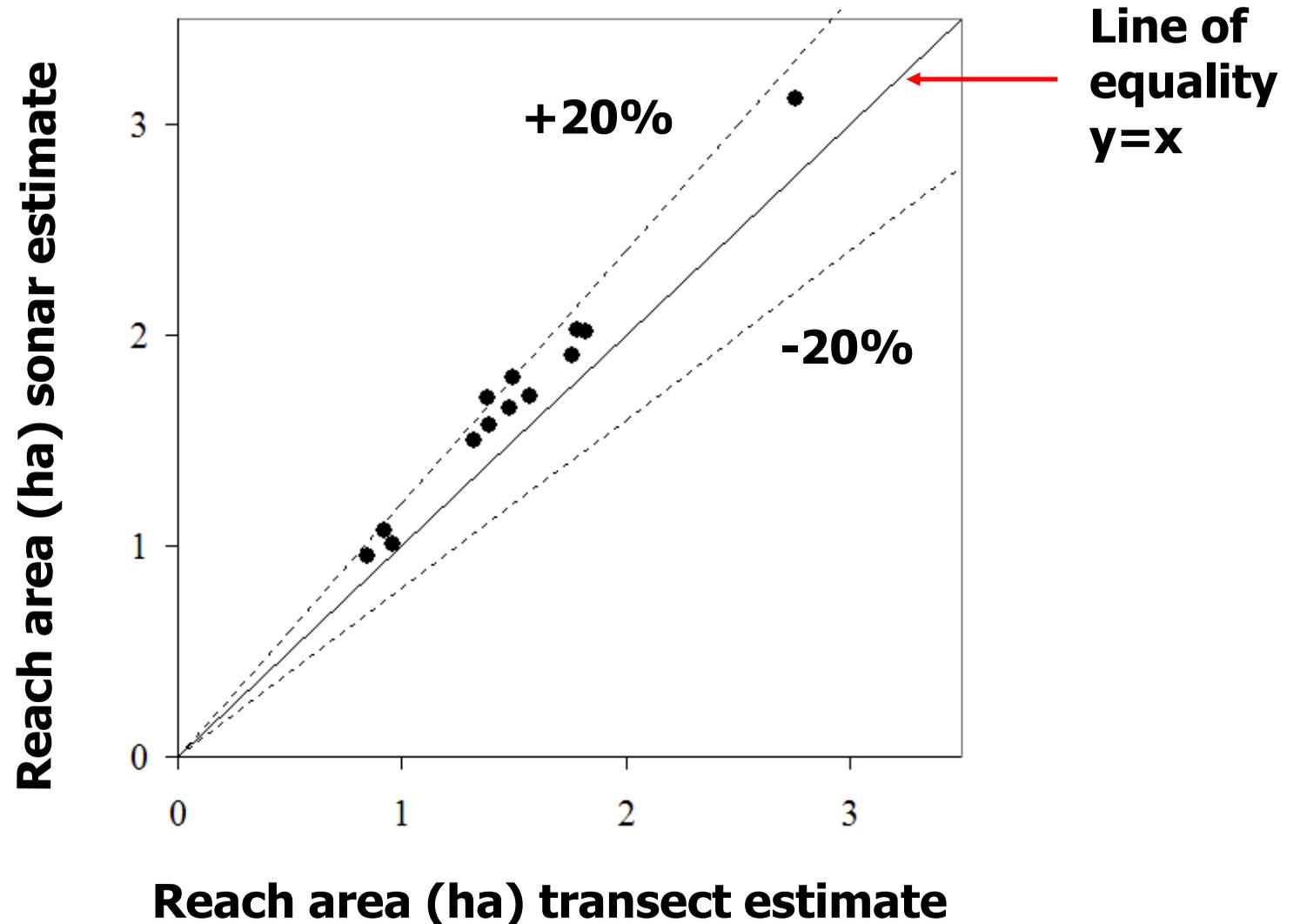


Measuring width in field

Repeated cross-channel measurements of bankfull channel width were used in combination with reach length to estimate total reach area in several study reaches. These estimates were compared to reach area estimates made from the sonar image maps of the same reaches. Results indicated that sonar estimates of width were consistently greater than our field-based bankfull channel measurements. Sonar-based estimates of reach area were typically 10% greater than field estimates. One potential explanation for the discrepancy was that width of the stream channel during the sonar survey was slightly greater than the bankfull channel width measured in the field. At the time this study was conducted, slant range correction was not available for Humminbird imagery. The effect of slant range correction should be explored as an alternative explanation for the discrepancy.

- Sonar channel width was consistently greater than field estimates of bankfull width
- One potential source for this discrepancy was width on survey date being greater than the bankfull width

Digitized stream banks approximate bankfull channel width

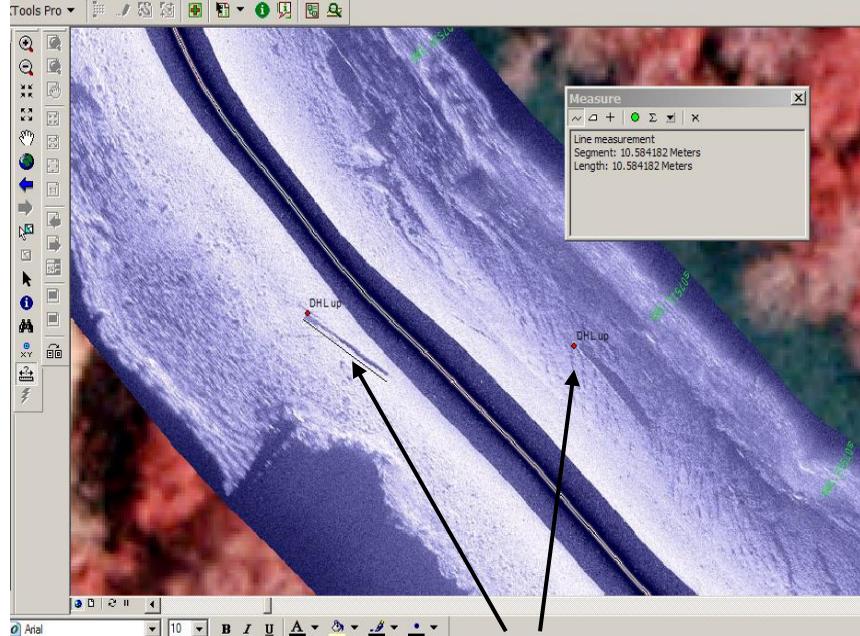


Measuring features

In addition to comparing channel width/area measurements, we identified a set of fixed, linear features in the SIMs that could be located in the field and measured. To assess y-dimensionality we identified individual deadhead logs that were oriented parallel to the boat path and measured these objects in both the SIMs and in the field. In the upper right image we show two of the logs that were measured in this set. To assess x-dimensionality we identified a set of bridges to measure between-abutment distances. In the lower left image we show one of the bridge abutment sets that was measured.

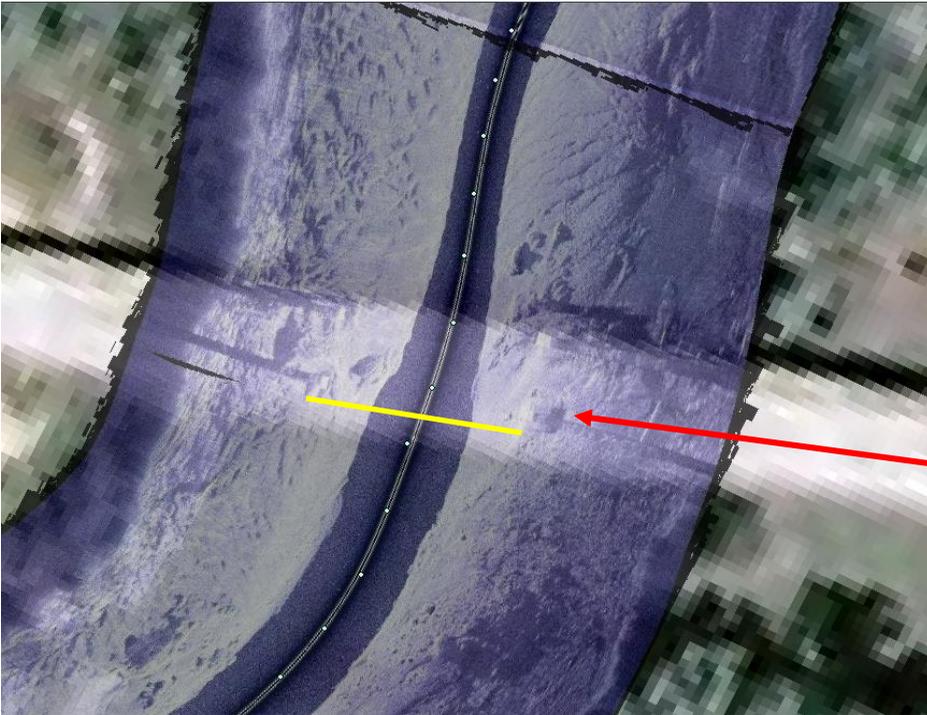
Dimensional Accuracy

Compare to field measurements



Are image dimensions corrected during transformation? Are rectified objects the right dimensions?

Strategy- measure fixed field objects (tapes, rangefinder), compare to sonar dimensions



Deadhead Logs (y dimension)

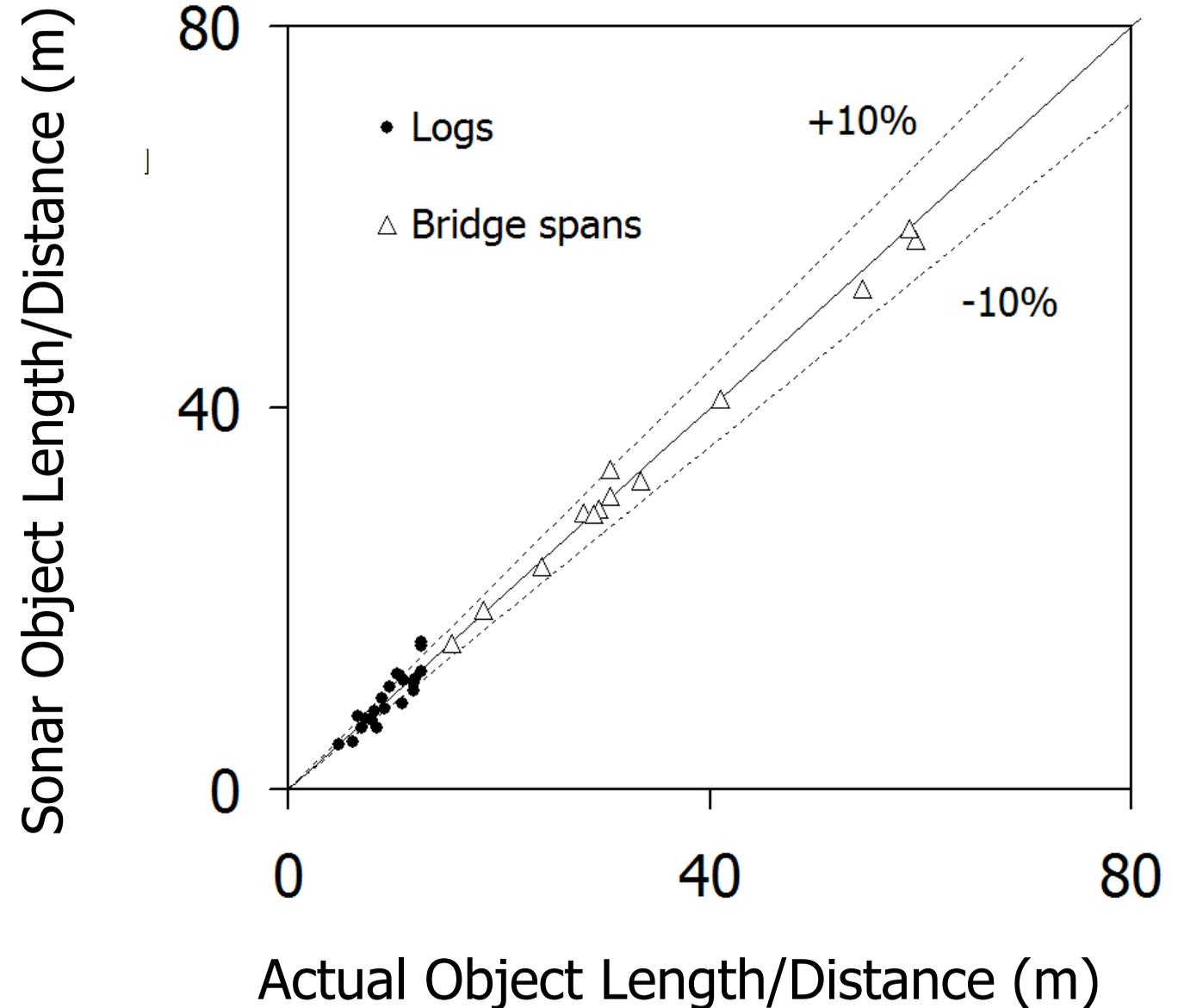
Bridge spans (x dimension)

Comparing measurements

If rectification effectively corrects the dimensional distortion inherent in raw sonar imagery, we should find that measurements made from apparent objects/features in the sonar image maps would be nearly identical to the measurements obtained from these same objects in the field. Plotting sonar object length against actual object length in a scatterplot should reveal a series of points that fall along the line $y=x$; this is exactly what we found. Differences between measurements rarely exceeded 10% in either direction.

The results of the bridge span measurements were particularly encouraging in the sense that bridge abutments appeared in imagery that included the water column (no slant range correction performed). Given that the water column imposes some dimensional distortion to features in the near-field portion of the image (as previously discussed), we were encouraged to find that such distortion did not affect the apparent x-dimensionality of these objects. In other words, bridge abutments appeared in their proper place in the image, rather than farther apart as might be expected given the inclusion of the water column between abutments. (These results also support our supposition that differences between sonar survey water levels and bankfull channel levels in the field led to differences in sonar vs actual reach area estimates, rather than the use of imagery that included the water column).

Dimensional Accuracy



Transformed dimensions

(Thom to Add)

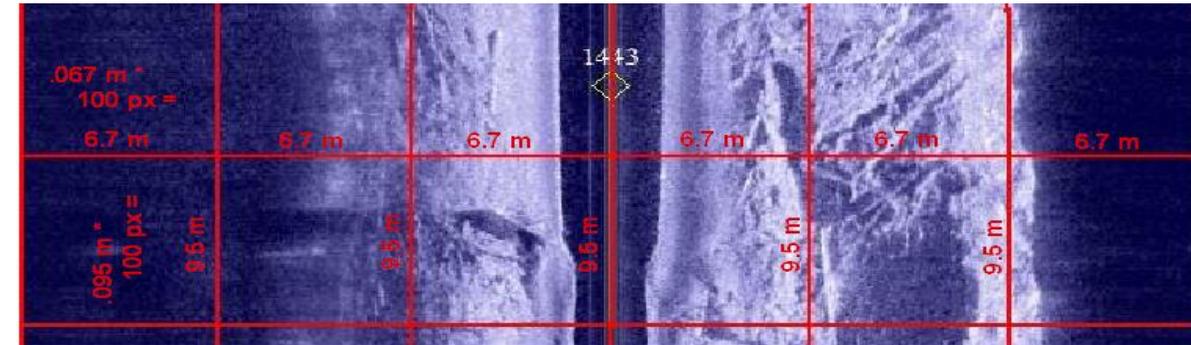
Grid dimensions based on .067m x .095 m pixel dimension (grid=100x100 pixels)

Grid dimensions measured in ArcView

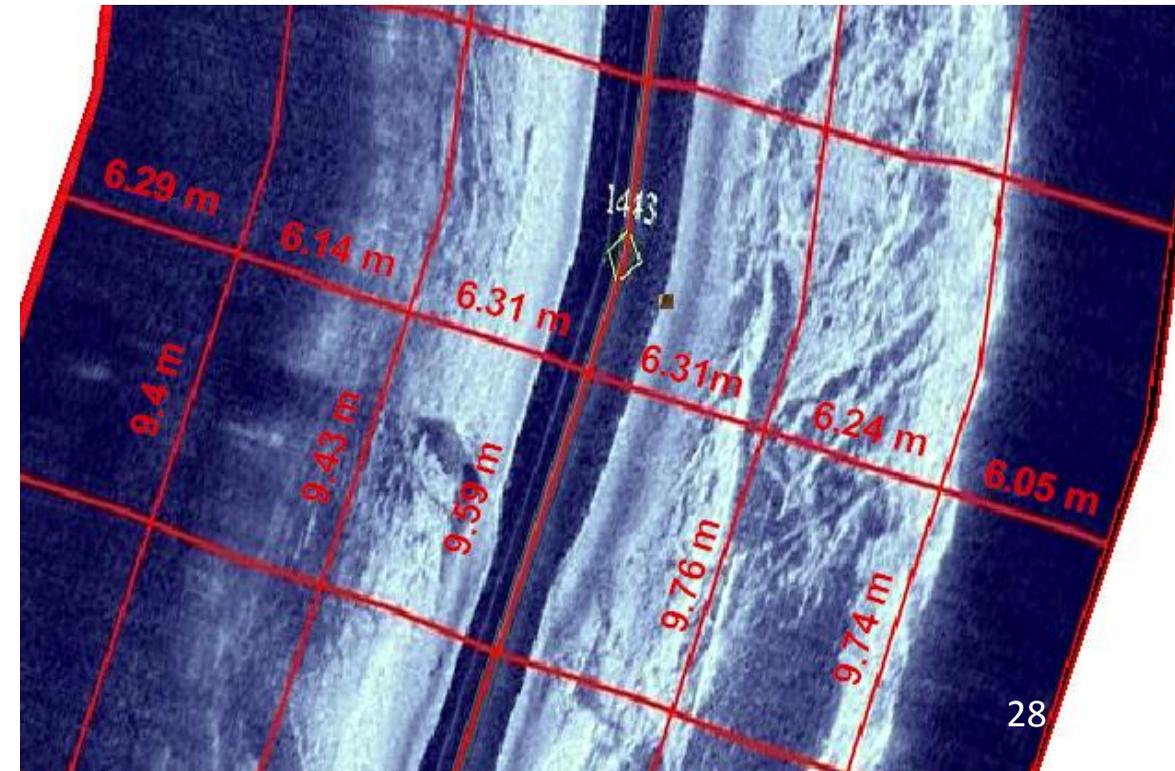
Note:
Geoprocessing algorithm effectively corrected variably sized pixels

Image Grid Measurements

Raw Image



Transformed Image



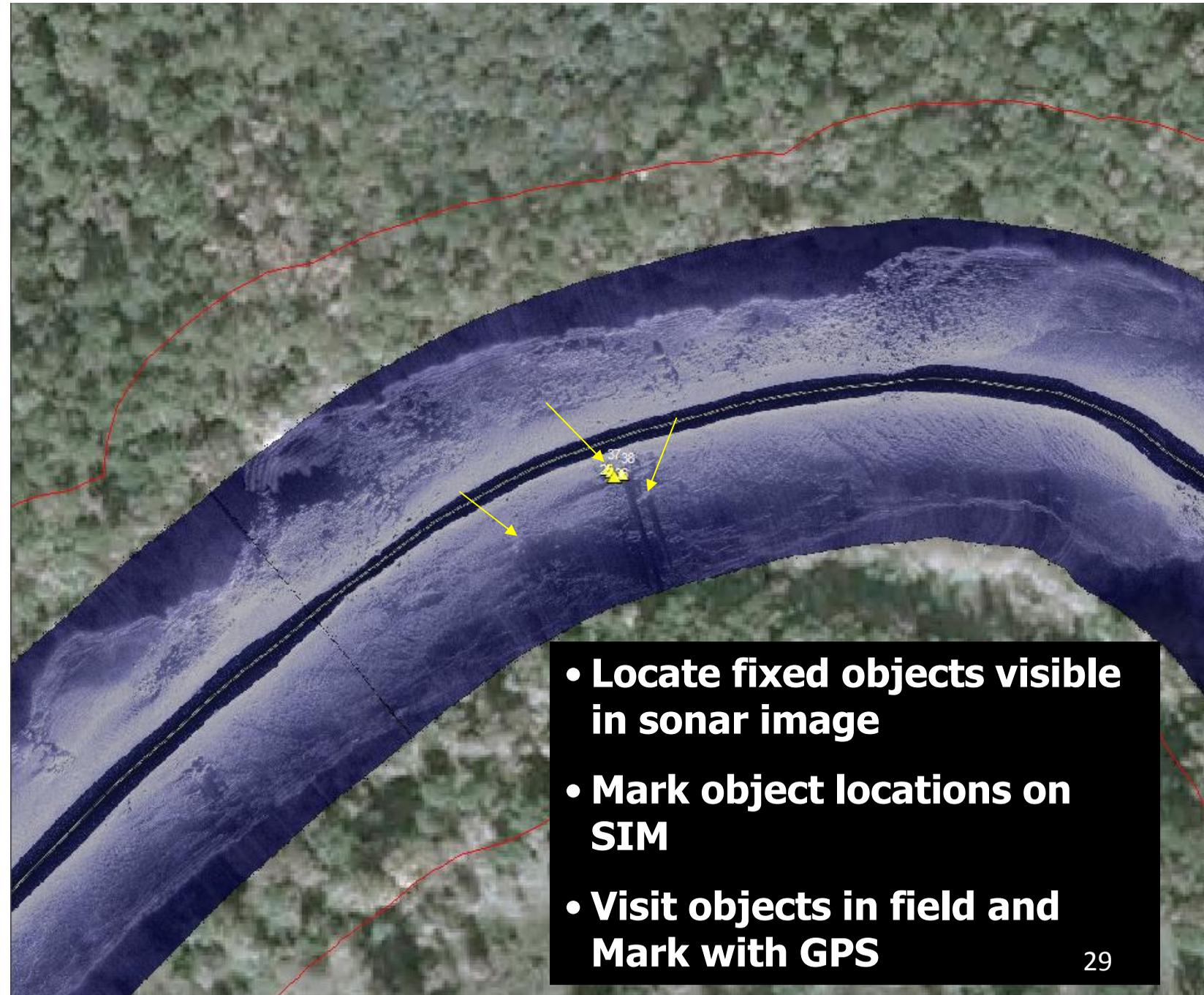
Geographical correctness

To assess positional accuracy is to determine whether apparent features in the sonar image map are located in their proper real-world, geographic positions. Positional accuracy, when reported as a +/- horizontal distance (meters), is a measure of the average positional difference between objects in the sonar image map and the same objects located in the field. This metric provides the expected error (i.e., offset) associated with relocating objects seen in the map; positional accuracy is relevant to an assessment of classification accuracy as well, as we will discuss.

To assess positional accuracy, we identified a set of fixed objects in the sonar image maps that included large boulders, cypress trees, and bridge abutments. The locations of these objects were marked on the map. Objects were then located in the field and marked with a hand-held GPS. Locations were plotted in ArcGIS, and XY coordinates for each object on the map and the object's corresponding field coordinates, were extracted for analysis.

In this example we identified three massive boulders in the middle of the Flint River that were visible above the water surface during the sonar survey (yellow arrows). The boulder closest to the water column was visited, and a series of GPS points was created for the actual location of the boulder (yellow triangles). The difference between the boulder in the sonar map, and the average position of the yellow triangles was the positional accuracy of this single object.

Positional Accuracy



- **Locate fixed objects visible in sonar image**
- **Mark object locations on SIM**
- **Visit objects in field and Mark with GPS**

RMSE

The coordinate sets of sonar image objects and their real-world locations are used to derive the root mean square error (RMSE) statistic. This value represents the average distance between an object in the sonar image map, and the same object located and marked in the field.

We evaluated positional accuracy in the Ichawaynochaway Creek substrate mapping study (8.0 meters) and lower Flint River substrate mapping study (4.6 meters). We believe the higher positional error associated with the Ichawaynochaway Creek map had to do with difficulty with GPS reception in the highly entrenched, canopied channel of this stream both during the sonar survey and during reference data collection, in addition to the fact that we did not correct any apparent GPS drift in the boat path during image geoprocessing. The Flint River has a much wider and open channel. Positional accuracy in the Flint River map was essentially equivalent to the stated accuracy of the GPS used during the project (3-5 meters).

These values have important implications for the assessment of classification accuracy, as this effort typically involves relocating specific points/sites to groundtruth. If a reference data point is located too close to the edge of a classified polygon, the risk of incorrectly assessing the substrate condition in an adjacent polygon due to GPS error and map position error is significant, and must be taken into consideration.

Positional Accuracy

Root Mean Square Error (RMSE):

Mean distance from SIM object to same object marked in the field with GPS

-an estimate of spatial error associated with relocating map objects or points (eg. groundtruth substrate points)

Ichawaynochaway Creek- 8.0 meters

Lower Flint River- 4.6 meters

*A spreadsheet enabling the calculation of RMSE can be obtained from the authors.

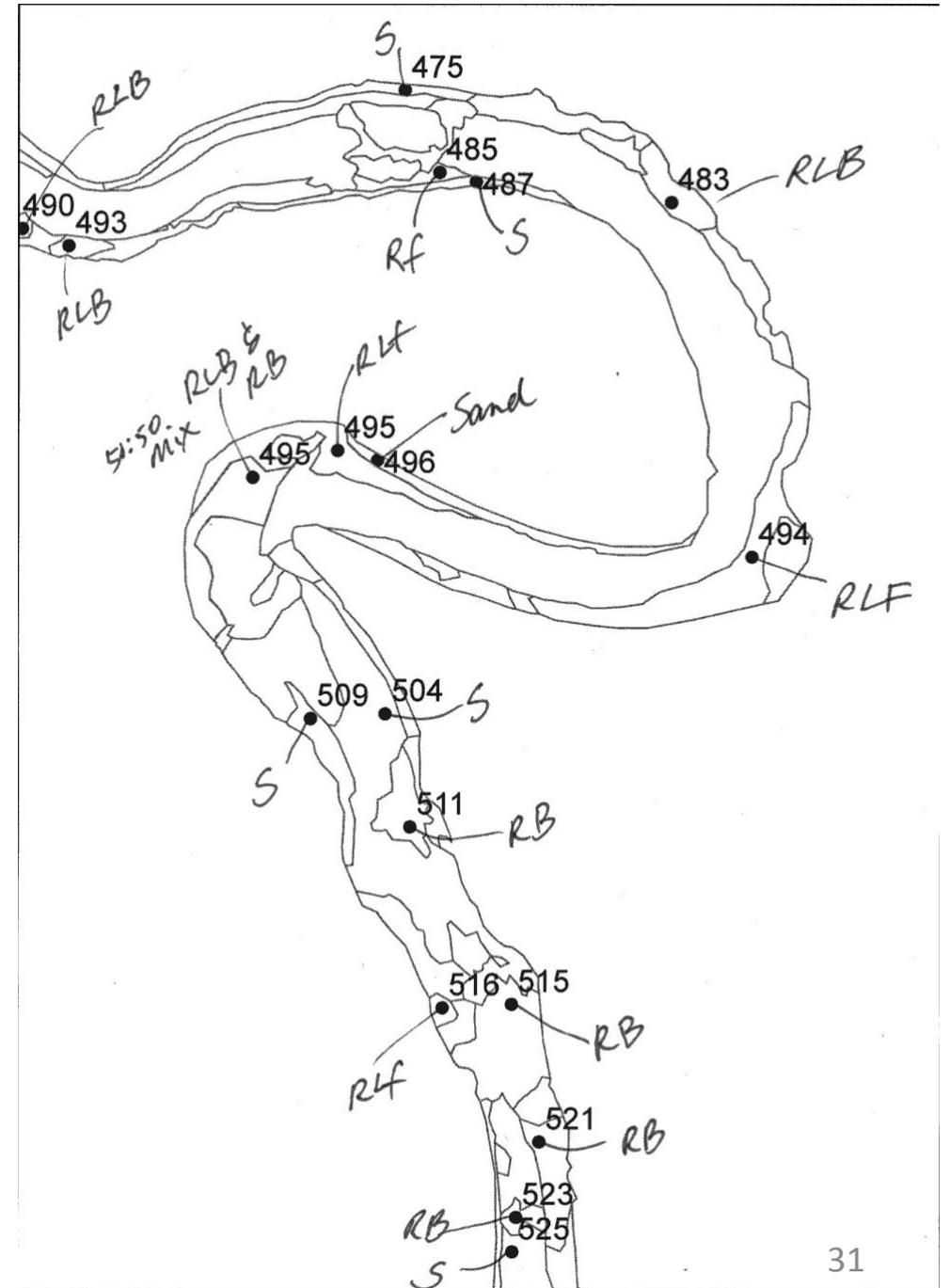
Thematic accuracy

To assess classification, or thematic accuracy of the map is to determine the level at which features in the map have been correctly classified. A defensible assessment of classification accuracy requires a reference data set that has been gathered in a statistically rigorous manner. To avoid bias in the selection of reference data sites, points can be randomly assigned to features in the map after the map has been produced.

In the adjacent figure, several randomly assigned points (black dots) appear within polygons in the completed substrate map. This reach, and many others were visited during a week-long period of reference data collection throughout the stream. Map print-outs were carried in the field for purposes of recording the actual, field-based assessment of the substrate class present in the polygon (see notes on map); these data comprise the reference data set. To maintain objectivity, map classification data should not be available during reference data collection.

Classification Accuracy

Need reference data set gathered in a statistically rigorous manner



Reference data points

A common rule of thumb regarding reference data collection is to gather at least 50 samples per class in the scheme. In the Ichawaynochway Creek study we visited 70 reference data sites per class; sites were identified by randomly assigning points to map polygons. Random points were buffered at 3 meters from adjacent polygons, and assigned prior to our assessment of positional accuracy for the map (i.e., 8.0 meters). As we learned, the 3 meter buffer demanded very high GPS accuracy in the field to avoid coregistration errors- or errors associated with an improper location of the reference data site in the field.

During our field assessments we also conducted a transect-based approach to substrate assessment in order to compare results and time investments between the two approaches.

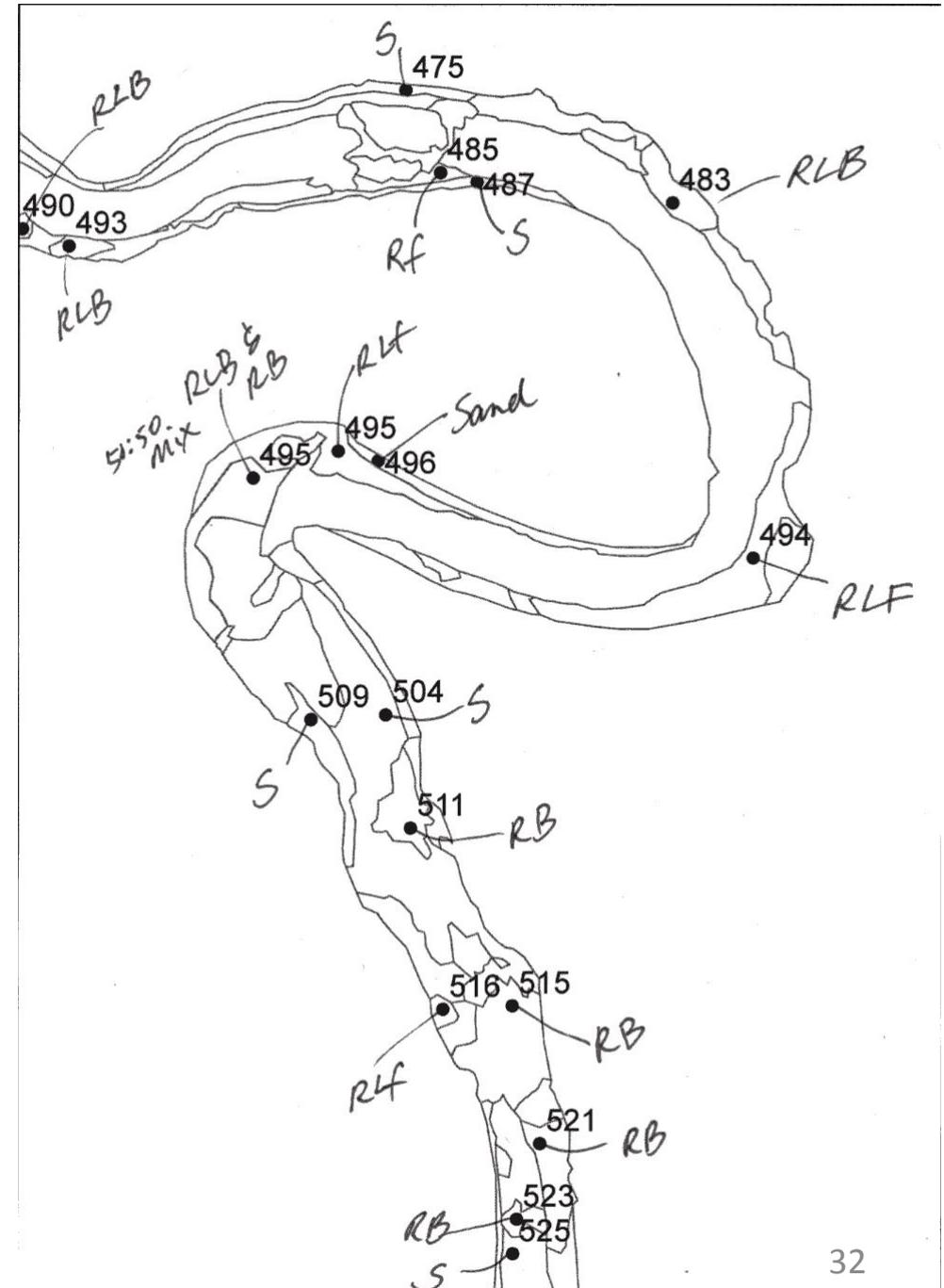
*Congalton and Green (1999) provide an excellent discussion of classification accuracy assessments.

Classification Accuracy

~70 points (IC)
randomly assigned
to each class visited
during field ground
truth

**-buffered at 3 m
from adjacent
polygons,
demanding high
GPS accuracy!**

-Transect-based
approach to
substrate
assessment also
conducted



Field groundtruth work

Visiting reference data sites in Ichawaynochaway Creek was accomplished using kayaks and a gheenoe. Substrates were inspected via snorkeling, wading, or diving during clear water conditions. We carried both a Trimble Recon and map print-outs to record reference data in digital and hard-copy formats. Using the Recon enabled us to easily integrate the reference data into the GIS project for analysis.

Classification Accuracy Assessment



**Ichawaynochaway
Creek**

-Snorkeling

-Wading

-Diving



Classification Accuracy Assessment

Field groundtruth work

Visiting reference data sites along the lower Flint River was accomplished using motorboats. Given the size and depth of the system, we turned to an alternative method of reference data collection that involved using a drop camera connected to a small television.

A certain level of water clarity is necessary to inspect substrate at depth in a river. In this case, low flows during the early winter season led to lower turbidity and permitted substrate visualization. The drop camera approach was much more efficient and cost-effective than using a dive team. In this study we used an Aqua-Vu camera.

Lower Flint River

- Drop-camera/TV screen with VHS recordings



Drop camera model

The particular AquaVu camera used during the Flint River study is no longer available for purchase. More recently we have acquired the system shown here called the EZ Spy Cam, and find that it works reasonably well. The mini-DVR enables the recording of videos of the underwater environment.

Drop camera and DVR



- 3.6 mm lens
- 410k pixel resolution
- Adjustable LED light

- 4 GB internal memory
 - Micro SD card slot
- AC/DC charge capabilities
- 4.3 inch screen



Confusion matrix

What do we do with reference data to analyze classification accuracy? The data are entered into a table called the standard error matrix or confusion matrix. The matrix provides a means of calculating and illustrating the errors of omission and commission in the map. Each cell in this matrix represents a single map vs. reference classification combination, or outcome. The rows in the matrix account for classified (map) data, and the columns account for reference (field) data. The diagonal cells in the matrix, highlighted here in green, are the cells representing the number of sites that were correctly classified for each substrate type in the map. All of the off-diagonal cells represent errors in the map. A simple sum of the total number of correctly classified sites (266) divided by the total number of reference sites examined (347) provides an overall accuracy statistic (77%).

Note that unknown areas (polygons that were assigned to a class of uncertainty) were excluded from the error matrix analysis.

Standard Error Matrix

Classified Data	Reference Data					Total points	User's Accuracy
	S	Rf	Rb	RLf	RLb		
S	60	6	1	0	0	67	90%
Rf	8	54	2	5	0	69	78%
Rb	0	8	59	1	3	71	83%
RLf	4	7	1	51	8	71	72%
RLb	0	3	16	8	42	69	61%
Total points	72	78	79	65	53	347	
Producer's Accuracy	83%	69%	75%	79%	79%		Overall Accuracy 77%

***Unknown areas excluded from analysis- 7% of total map area**

User vs Producer Accuracy

Let's consider the difference between User's and Producer's accuracy as revealed in the error matrix. When assessing accuracy in Ichawaynochaway Creek, we visited a total of 67 sites classified sandy in the habitat map. Of the 67 sites groundtruthed, 60 sites were confirmed as sandy substrate in the field (6 sandy sites were actually rocky fine Rf, and 1 site was rocky boulder Rb). Let's say we wish to use this map to set traps for snapping turtles in sandy substrate areas. User's accuracy represents the likelihood that a sandy polygon in the map has been classified correctly. That is to say, when we visit an area identified in the map as sandy, the user's accuracy provides the likelihood that we will indeed find sandy substrate. User's accuracy for the sandy class is thus 60/67 or 90%.

Let us also consider, however, the fact that the map maker did not succeed at identifying all of the truly sandy areas in this stream. Twelve sites were identified in the field as sandy substrate that were classified as another substrate in the map (8 were classified rocky fine Rf, 4 were classified limerock fine Rlf). Producer's accuracy, or the ability of the map maker to correctly identify all of the sandy areas that truly existed in the map, is thus 60/72 or 83%.

Standard Error Matrix

Classified Data	Reference Data					Total points	User's Accuracy
	S	Rf	Rb	RLf	RLb		
S	60	6	1	0	0	67	90%
Rf	8	54	2	5	0	69	78%
Rb	0	8	59	1	3	71	83%
RLf	4	7	1	51	8	71	72%
RLb	0	3	16	8	42	69	61%
Total points	72	78	79	65	53	347	
Producer's Accuracy	83%	69%	75%	79%	79%		Overall Accuracy 77%

Sandy/rocky fine errors

A lot of learning and training can take place during this phase of the mapping process. Needless to say, one must evaluate classification accuracy and study the results closely in order to improve map making skills. Let's examine one particular type of error that occurred with some frequency in the map. The red cells in the matrix identify cases where polygons classified in the substrate map as sandy were actually rocky fine (n=6), and polygons that were classified in the map as rocky fine that were actually sandy substrate in the field (n=8). These two substrates are indeed quite different in nature, so this type of error is one that did concern us.

Each error can be scrutinized in an attempt to determine why the mistake was made, and how to avoid it in the future. Lessons can be applied to future map projects, and new insight can be used to edit the map if deemed appropriate. Let's look more closely at just one example of the sandy/rocky fine confusion.

Standard Error Matrix

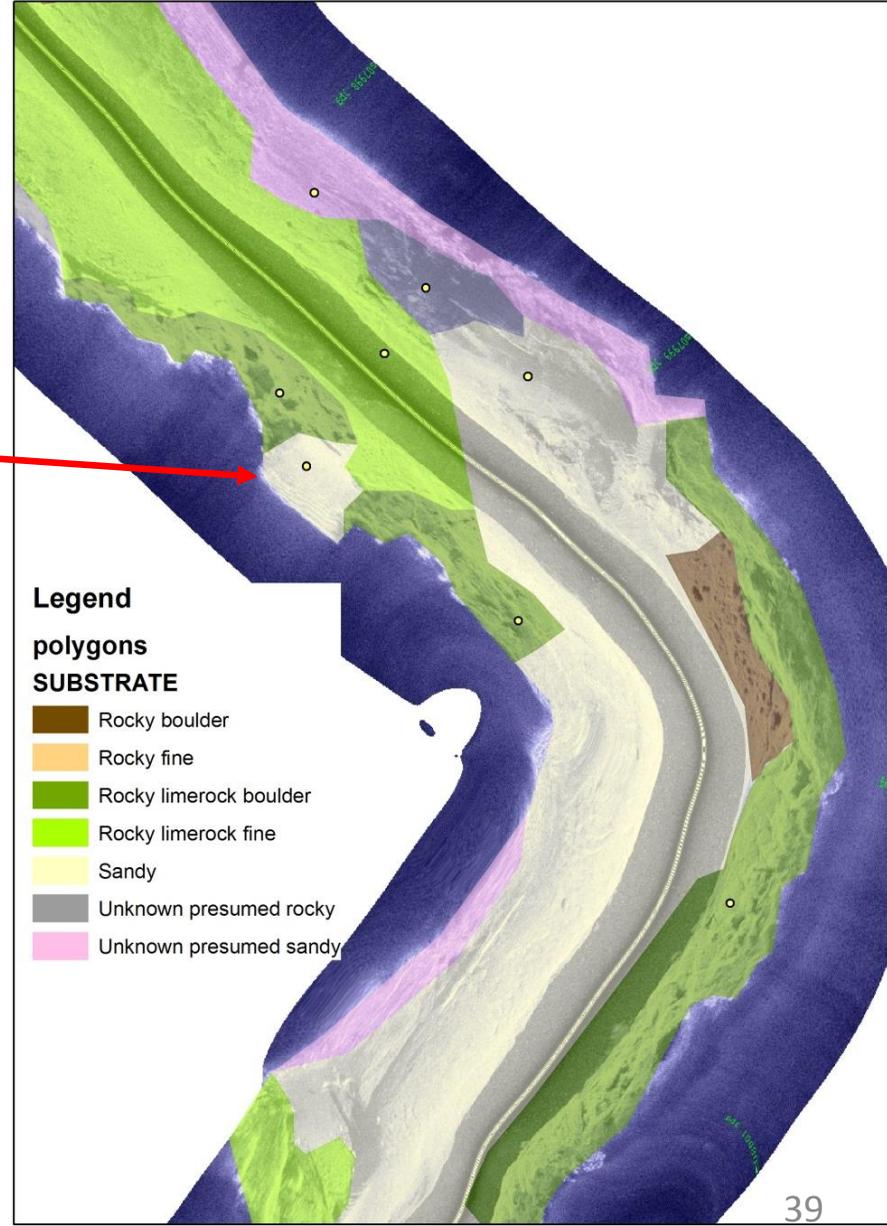
Classified Data	Reference Data					Total points	User's Accuracy
	S	Rf	Rb	RLf	RLb		
S	60	6	1	0	0	67	90%
Rf	8	54	2	5	0	69	78%
Rb	0	8	59	1	3	71	83%
RLf	4	7	1	51	8	71	72%
RLb	0	3	16	8	42	69	61%
Total points	72	78	79	65	53	347	
Producer's Accuracy	83%	69%	75%	79%	79%		Overall Accuracy 77%

Polygon classified sandy

In this example, we visited a small polygon along the margin of the creek that was classified as sandy substrate in the map. Note that this small polygon was bounded by an outcrop of limerock boulder in upstream and downstream directions.

Example of misclassified polygon

This polygon (70 m²) classified Sandy



Polygon visited in field

We pulled up to the reference data site during our groundtruthing expedition and this is what we found. The map polygon in question is the dry area of exposed substrate that the gheeno is pointing toward. Note the outcrop of limerock boulder visible just upstream of the reference site. It's hard to tell what the substrate composition of the reference site is from here- let's take a closer look.

Example of misclassified polygon



The actual substrate

The predominant substrate composition of this polygon was actually a gravel-pebble mix rather than sand. According to the classification scheme, this material should be classified as rocky fine. This polygon was misclassified due to a failure to differentiate the sonar signature of gravel and pebble material from that of sand. Recall that the pixel resolution of 455kHz imagery is 6 cm. The red box approximates a 6x6 cm pixel. Clearly, these particles are smaller than the individual pixels of the sonar image map. In other words, we would not expect to see individual gravel particles in the sonar image.

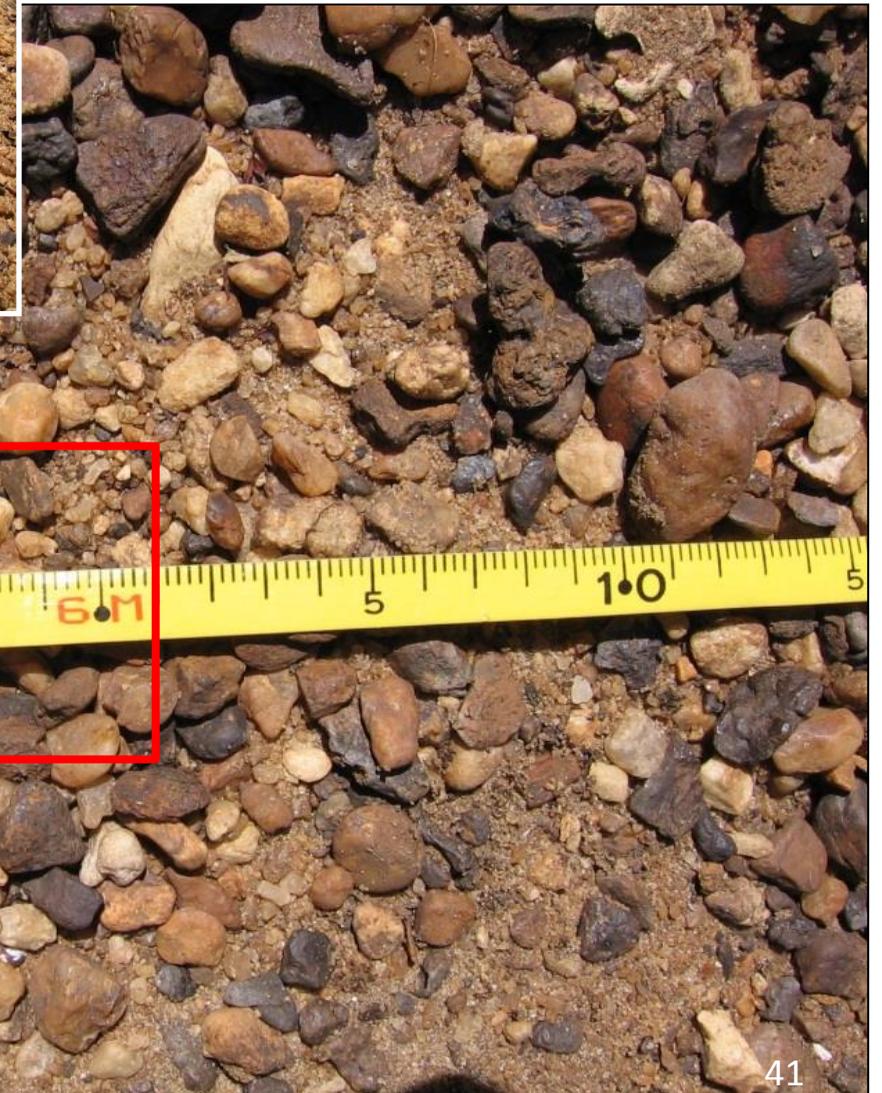
More work needs to be done to evaluate the mapping of gravel substrate with the Humminbird SI system. The identification of gravel might require that features at a coarser scale are used to discriminate gravel from sandy substrate (for example, the absence of ripple patterning in gravel patches). Alternatively, the use of 800 kHz might provide the image resolution necessary to improve the discrimination of gravel substrate.

Gravel proved to be quite rare in Ichawaynochaway Creek. The rarity of the substrate class provided very limited opportunities for training on this substrate type. Future work with gravel mapping must be undertaken in systems that provide greater opportunities for training on gravel discrimination.

This concludes our discussion of map accuracy assessment. Let's turn the discussion to a very important question about time investments.

Gravel-Pebble Mix

**Red box represents
~6X6 cm pixel**



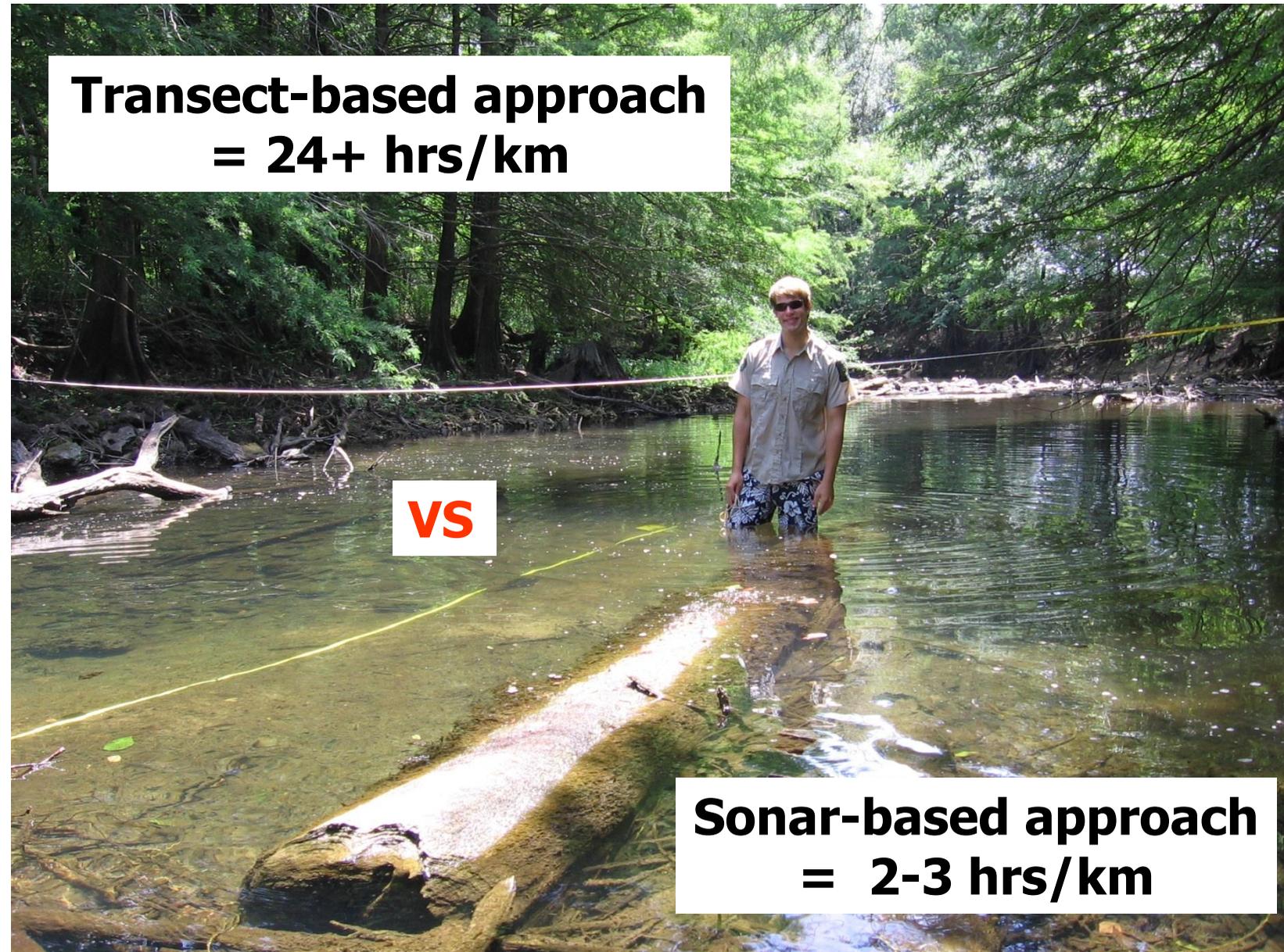
Time investments

How much time does this whole process of habitat mapping require? Over several mapping projects we have maintained records of time invested during various steps of the mapping process. Along the way, Thom completed several improvements to the GIS Sonar Toolkit that involve automation of processing steps, further reducing time investments.

A transect-based approach to substrate assessment required 24+ man hours per kilometer for us to complete. This approach assessed only the coverage of substrates along transects spaced at 20-meter intervals. In many places, this approach will not be feasible due to size, depth, and turbidity.

In contrast, the entire sonar-based approach to mapping habitat required only 2-3 hours per kilometer to complete. The specific length of time will vary depending on the complexity and size of the system, in addition to the variety of elements being mapped. These estimates included the mapping of large woody debris, a very time intensive step of the process. Nonetheless, the sonar-based approach represents the time savings of an order of magnitude to project completion. Moreover, the sonar habitat map, unlike the transect-based assessment, provides complete bank-to-bank spatial coverage- a complete census of the entire study area is provided.

How much time?



Potential limitations

Sonar habitat mapping is certainly not the answer to every habitat assessment need. To be fair, let's review some of the potential limitations that have been identified during our discussions. Sonar resolution is highly important, yet influenced by factors that are sometimes out of our control. Careful planning and execution of survey work is necessary. Discrimination of small objects and fine substrates can be challenging. Sonar shadowing, bank distortion, and variable channel width are potential sources of missing data. The overall quality of map products will definitely be influenced by study design, execution, and the experience and skill of the map maker(s). Sonar habitat mapping requires some hardware and software, although these resources are typically available to natural resource professionals. Accurate GPS positioning is required in the field for georeferencing imagery, and navigable conditions with an average working depth of at least 3-4 feet is probably necessary (although more work is required to truly evaluate performance limitations in shallow environments).

Limitations of Sonar Mapping

- Sonar resolution affected by system width, higher range setting= decreased resolution
- Discrimination of fine substrates challenging- requires more investigation
- Sonar shadowing & bank distortion= missing data
- Map accuracy affected by study design/execution and interpreter's experience
- Hardware/software and training required
- Accurate GPS signal required, adequate depth for navigation and imaging

Why sonar mapping?

On the other hand, low-cost sonar habitat mapping provides a rapid, accurate, flexible, and inexpensive means to map and quantify elements of physical habitat and other features in turbid, non-wadeable streams at the landscape scale.

Side scan sonar has been around for 50+ years, yet the business of mapping habitat in inland waters has simply not become commonplace- Why? We believe the reason is lack of access to low-cost equipment, tools, and training. Indeed, a major goal of the sonar habitat mapping initiative is to provide the tools and training to overcome this hurdle. We hope that this guidebook and the tools that accompany it contribute significantly toward this effort.

Benefits of Sonar Mapping

- **Rapid, accurate, flexible, & inexpensive means to map and quantify habitat in turbid, non-wadeable systems at landscape scale**

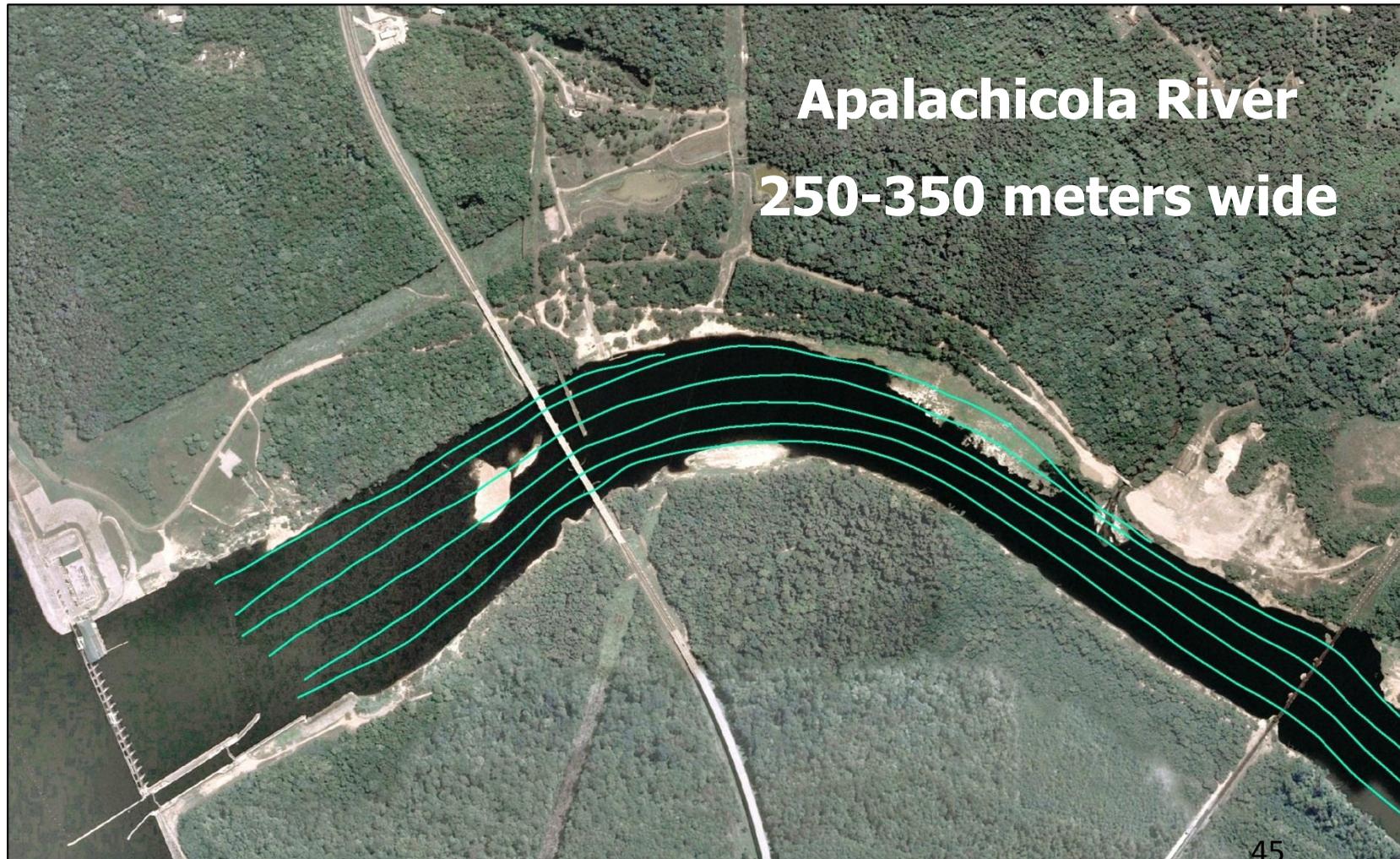


Scaling up

What are some of the additional benefits of low-cost, sonar habitat mapping? Scaling up in larger and wider river systems is possible. Sonar ranges can be increased to 150-170 feet per side at 455 kHz and still provide high resolution imagery. The benefits of surveying with multiple parallel passes, using lower range settings to maintain higher image resolution, are available.

Benefits of Sonar Mapping

- **Scaling up to large/wide river systems possible**



Integrating biological data

Another major benefit is that sonar based habitat maps can be applied to ecological research, conservation planning and design, and monitoring. The map is a tool, and it should be put to good use!

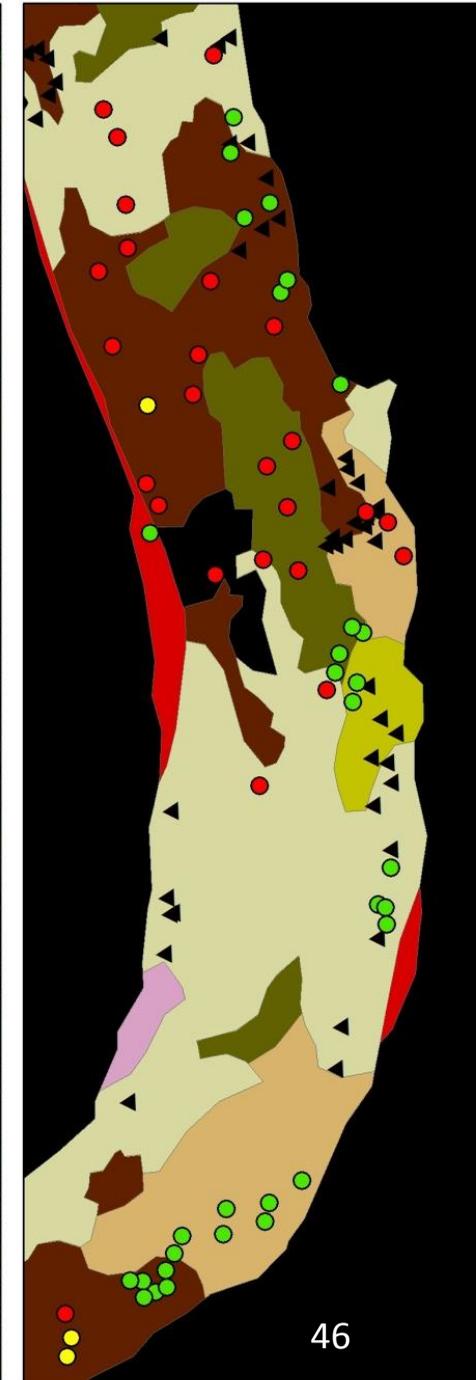
Since sonar habitat maps are produced within a GIS platform, spatial biological data can easily be integrated and linked to physical habitat, unlocking a trove of potential analyses. This integration enables studies of organism-habitat associations and behavioral patterns at the landscape scale. Given the availability of terrestrial data layers, the associations between landuse and physical aquatic habitat can also be explored.

Fortunately for us, terrestrial ecologists have been developing landscape level approaches to analyzing organism-habitat relationships for some time now. A robust field of research and publications is available for mining ideas and models. Now that the tools and techniques are available to fill the aquatic habitat gap, it's time to take landscape ecology to the water!

Applications

- **Sonar habitat maps can be integrated with other spatial datasets to yield great analysis potential**
 - **Studies of organism-habitat associations and behavioral patterns**
 - **Landuse/landcover associations with instream habitat**
- **Monitoring habitat change over time**

*These figures from the study – Gocłowski M.R., A. J. Kaeser, and S. M. Sammons (2012). Movement and habitat differentiation among adult shoal bass, largemouth bass, and spotted bass in the upper Flint River, Georgia. North American Journal of Fisheries Management.

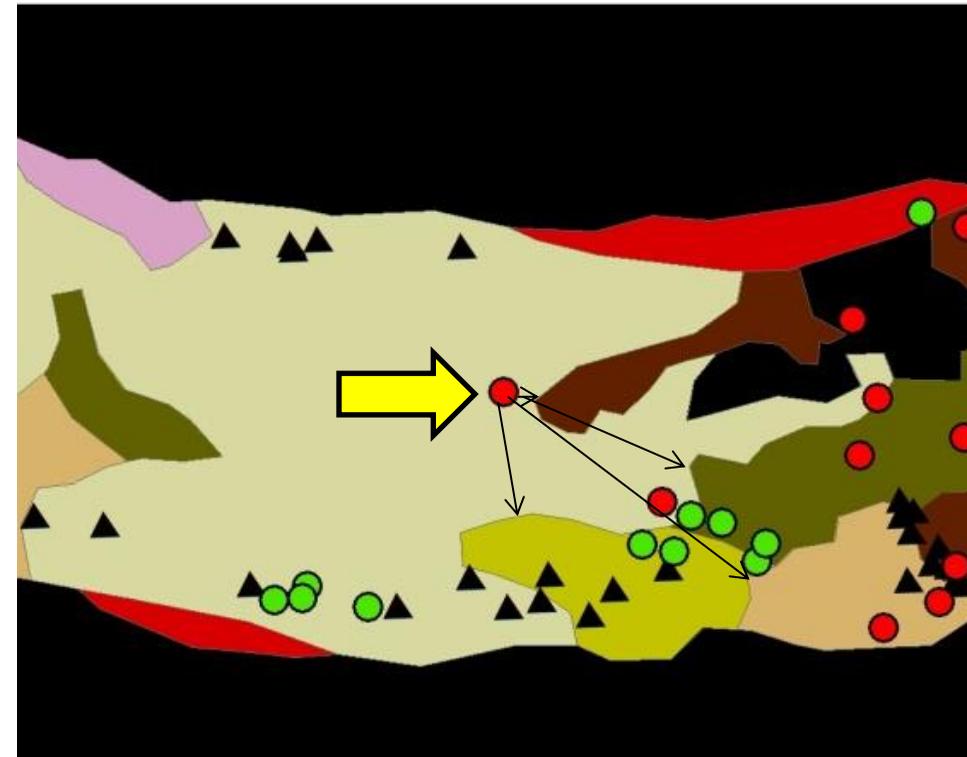


Distance-based approach

Extracting detailed habitat data associated with the locations of animals or samples obtained in the field is quite easy and efficient within a GIS. Because the map represents a full census of available habitat, it becomes possible to adopt a distance-based approach to habitat analyses (see Conner et al. 2004). The distance-based approach examines the distances from each point sample to each habitat element, thereby preserving and incorporating the spatial complexity of the data in the analysis. For example, consider the red dot identified by the yellow arrow in the adjacent figure. This dot represents a single location of a shoal bass in this river. The fish appears to have been located over sandy substrate (light tan color). A classification-based approach to habitat analysis would look only at the association of this fish point with sandy substrate. On the other hand, note how close this fish was to rocky boulder substrate (the dark brown color). A distance-based approach finds the nearest distance to each available substrate class in the map (black arrows), thus creating a multivariate vector of habitat association for each fish location that is analyzed. The distance-based approach is also very robust to positional errors inherent in the habitat map and sample locations, and thus is an approach with several noteworthy merits. Consider the possibility that this fish was actually positioned over the rocky boulder substrate, but GPS error put the fish over sandy substrate. The distance-based approach helps to mitigate the effects of such errors in the analysis.

Spatial Analysis

- **Distance from each fish location (or sample) to nearest habitat elements found**
- **Spatial complexity preserved and incorporated into analyses**
- **Approach robust to positional errors**



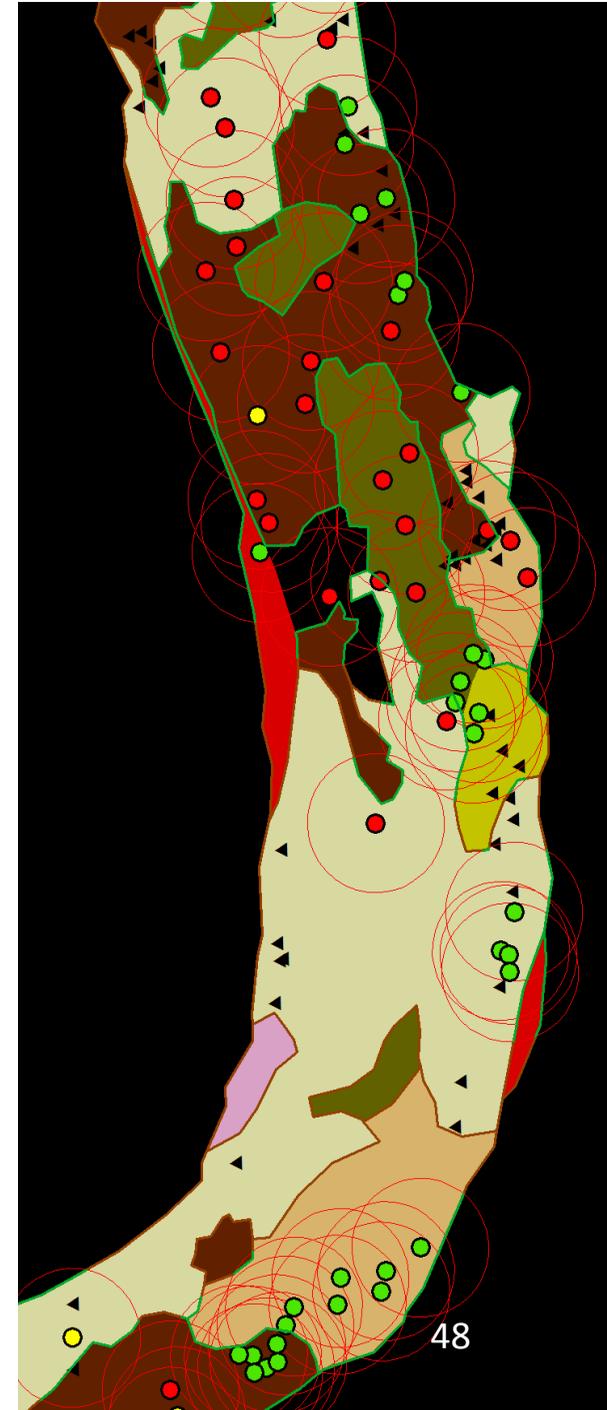
Extracting map data

A variety of ecologically relevant habitat metrics can be extracted from a habitat map using ArcGIS tools. We have mentioned distances to nearest substrates as a multivariate measure of substrate affiliation. It is also possible to buffer sample locations (as illustrated by red circles around fish locations on right) and summarize features within buffers, for example the quantity of woody debris or edge.

Spatial Analysis

Variables (examples)

- Distance from each fish location to edge of nearest substrate class
- Distance to bank
- Distance to nearest LWD
- Count of LWD in 15m buffer
- Edge within 15m buffer



Study change over time

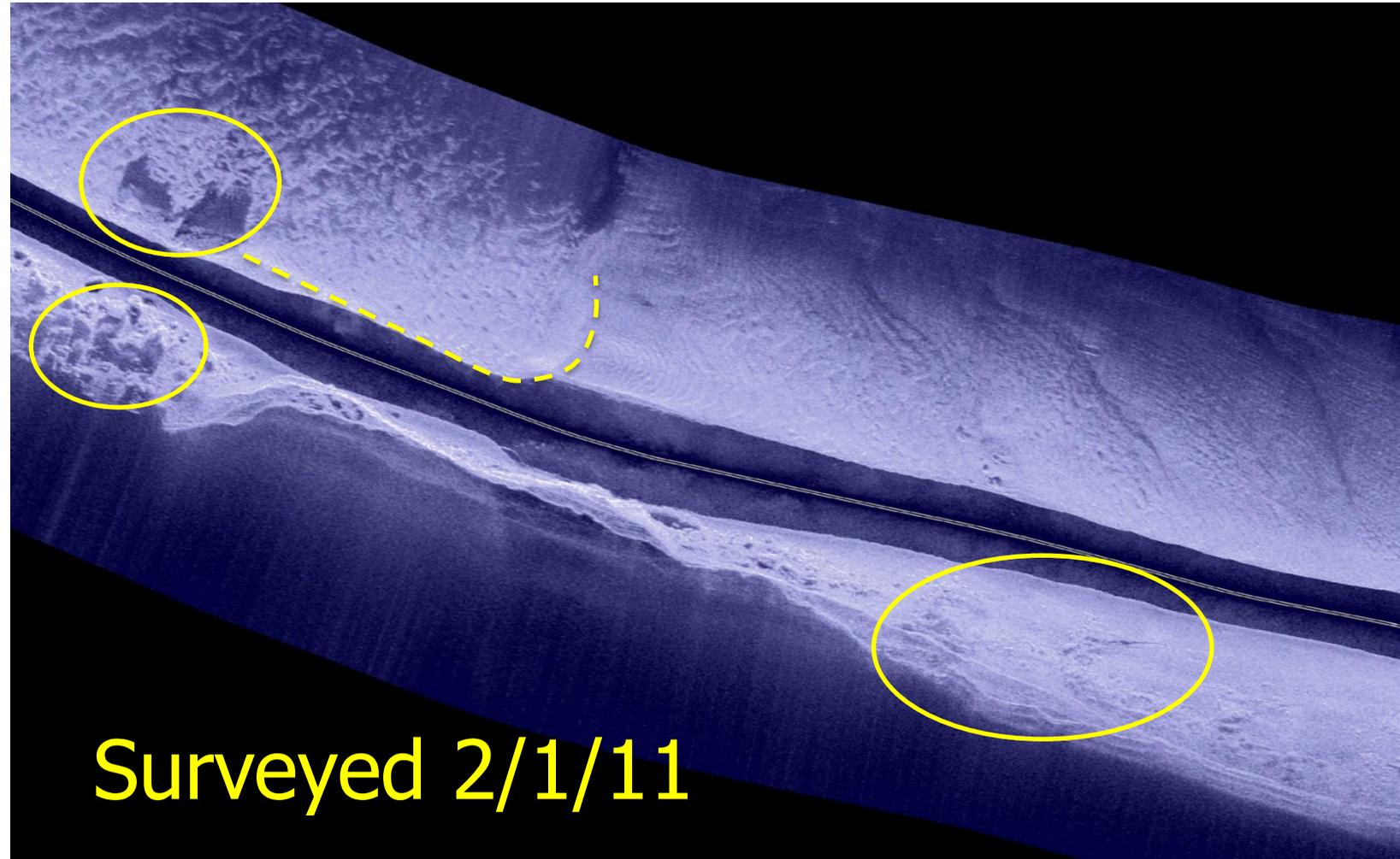
Like any air photo or lidar data set, the sonar image map represents a snapshot in time. Sonar mapping can be applied in a time-lapse fashion (i.e., multiple surveys over time) to monitor and study potential changes in habitat. Just as a forest ecologist studies decadal trends in forest composition, why not examine trends in substrate composition of the riverbed? What might we learn?

We've only just begun to casually look at how substrate composition can change over time in some of the rivers we frequent. In some cases, the changes are quite striking. The example provided here comes from a pair of surveys covering a reach of the Altamaha River. On the left side of the image we find a group of large boulder-like hard substrates (rock or hard clay). Downstream of this outcrop is the leading edge of a massive sand wave or dune, outlined by the dashed yellow line. Further downstream is an area along the right bank that has cobble sized rock or clay composition, barely visible at this scale. This image was produced February 1, 2011.

*The fundamental goal of this project was to identify the limited occurrences of hard bottom substrate available as potential spawning habitat for sturgeon, not the documentation of change over time.

Applications

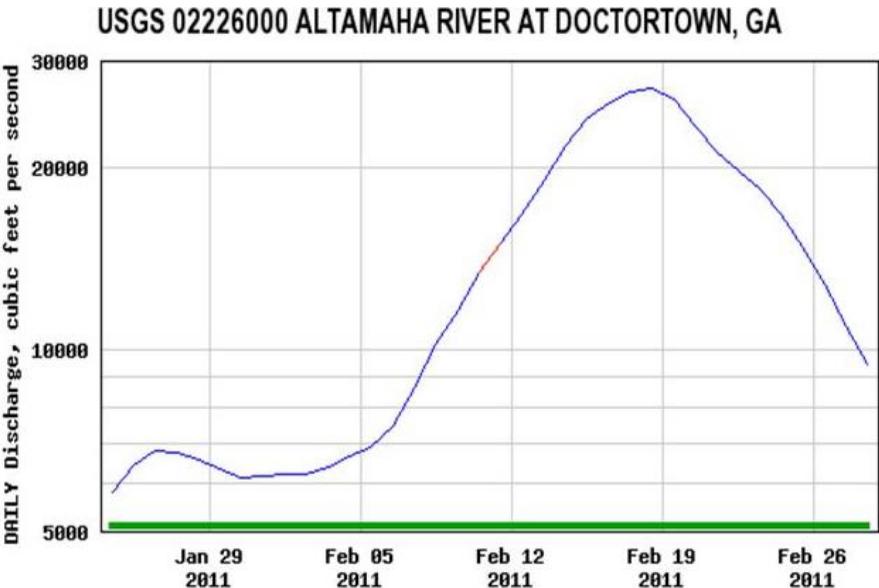
Quantifying changes in habitat



Change over time

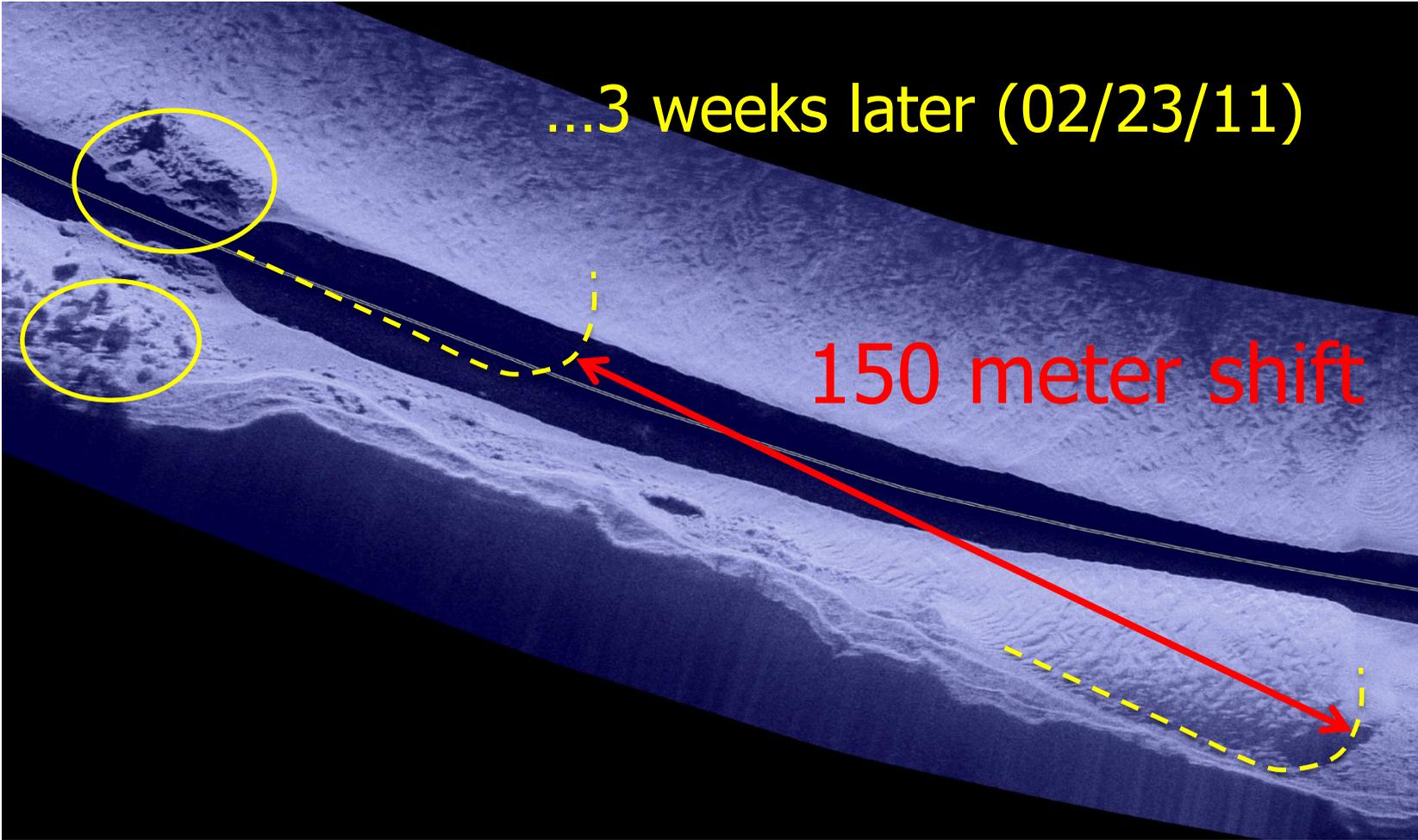
Three weeks later this reach was resurveyed. Some impressive changes had occurred to substrate composition. The clay outcrop/boulder area in the upper left had been scoured clean of some sand, and the massive sand wave from February 1 had vanished. The sand appears to have been transported and deposited approximately 150 meters downstream of its former location, where it now smothers the area of cobble-sized material along the right bank. These changes were associated with a runoff event that occurred between surveys (see hydrograph below).

Aquatic systems will likely change at varying rates, and in response to unpredictable events. Does this negate sonar mapping- of course not! Our world is constantly changing, yet we rely on maps all the time. The potential for change should be considered when producing and applying sonar map products.



Applications

Quantifying changes in habitat



* Flood stage is ~90,000 cfs for the gauge location, so the runoff event associated with this change was not a flood.

Lakes and Reservoirs

Admittedly, our emphasis throughout this guidebook has been on streams and rivers, yet the principles of sonar mapping apply to work in lentic waters. Several years ago we prepared a presentation for the Reservoir Committee of the American Fisheries Society that included demonstration work conducted in a few reservoirs. It's worth briefly discussing a few of the considerations associated with adapting sonar mapping to such environments that have not been addressed in previous discussions.

Lentic Applications

Adaptive Strategies for Mapping Habitat with SSS in Reservoirs



Issues of scale

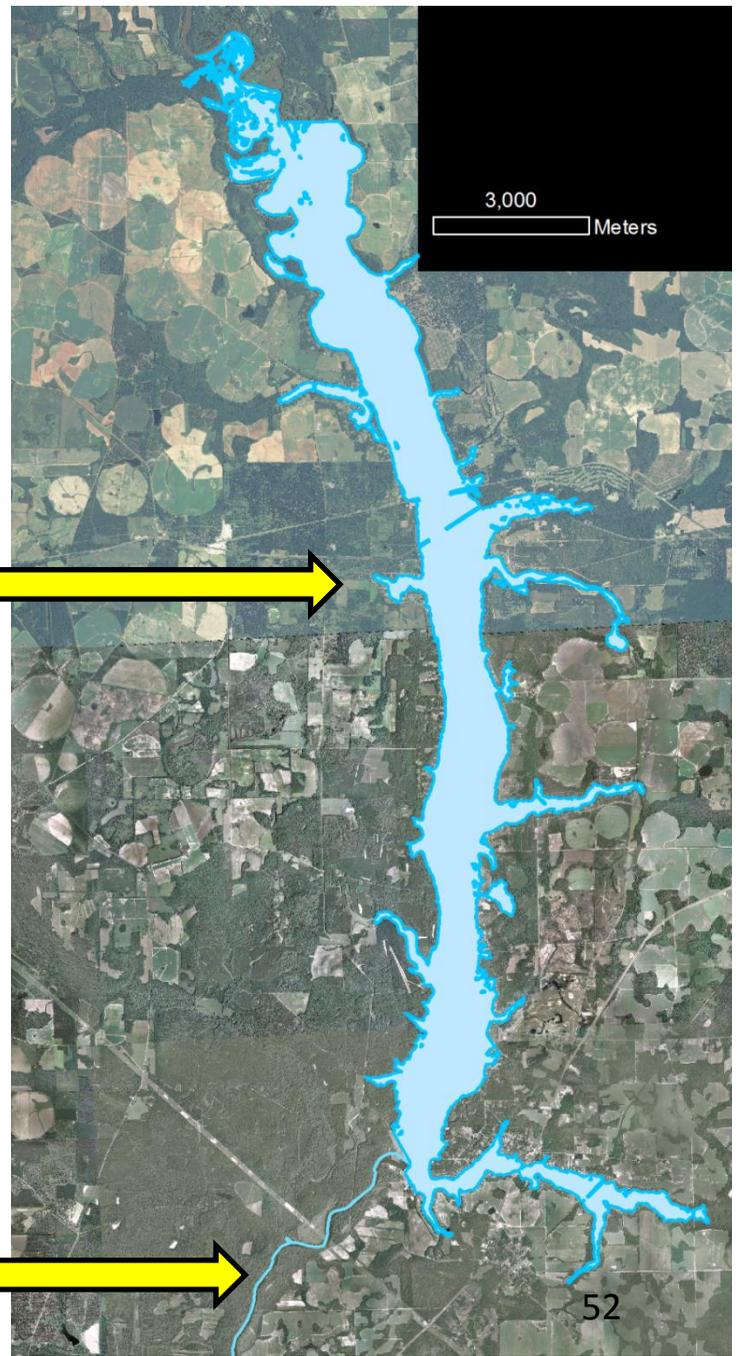
One of the outstanding challenges of sonar mapping in a lentic system, such as the reservoir shown here, is the overall scale of the system. Reservoirs are typically wider and deeper than rivers. Even small, relatively non-dendritic reservoirs such as Lake Blackshear, in this example, can have an overwhelming total perimeter length. To map only shoreline habitat in this reservoir (187 km) would require an effort that spanned multiple days in the field. To put the scale of this system in perspective, consider that the thin blue line at the downstream (lower) end of this reservoir is the lower Flint River, a system we have frequently referenced throughout the guidebook.

Lentic Applications

- Width
- Perimeter

Lake Blackshear
Area- 3,300 hectares
Perimeter= 187 Km

Lower
Flint
River



Addressing scale

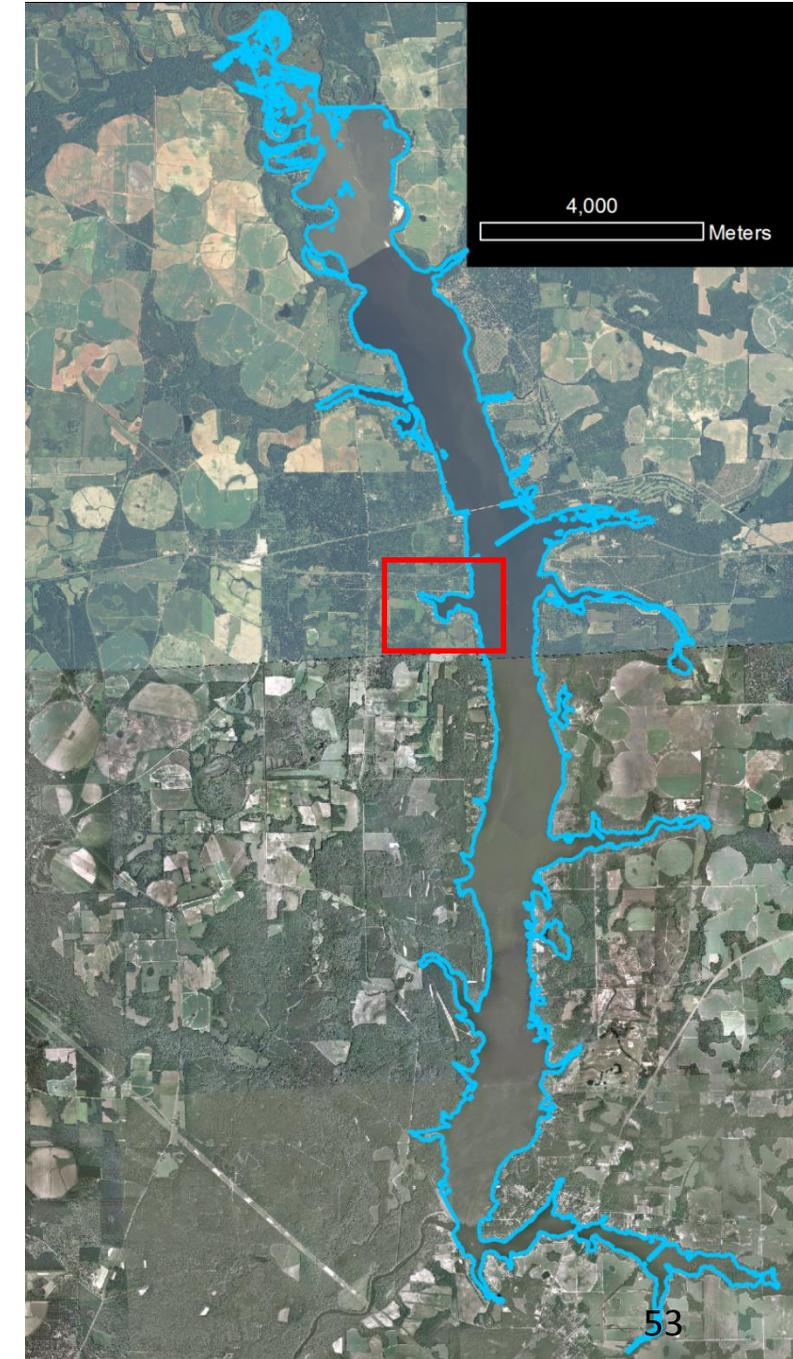
To handle issues of scale associated with lentic systems we might consider targeting only shoreline habitat, or consider stratifying the reservoir and prioritizing areas for survey work. If deemed logistically and practically feasible, the entire system could be mapped at high resolution using a parallel transect approach.

In our demonstration work, we selected a few coves of Lake Blackshear for shoreline mapping. Selected sites might be those targeted by a state regional fisheries team for standardized monitoring of sportfishes, for example.

Scale

How to address:

- Target shoreline habitat
- Stratify/prioritize areas for survey
- Use transects for complete coverage at high resolution



Mapping sub-units

In this example, we targeted a cove of Lake Blackshear called Pecan Slough. The total perimeter of this cove was 2.5 km; the field survey and image processing was completed in approximately 60 minutes.

Shoreline Mapping

- Target specific areas like coves



Pecan Slough

2.5 km
perimeter

~ 60 min to
capture and
process data

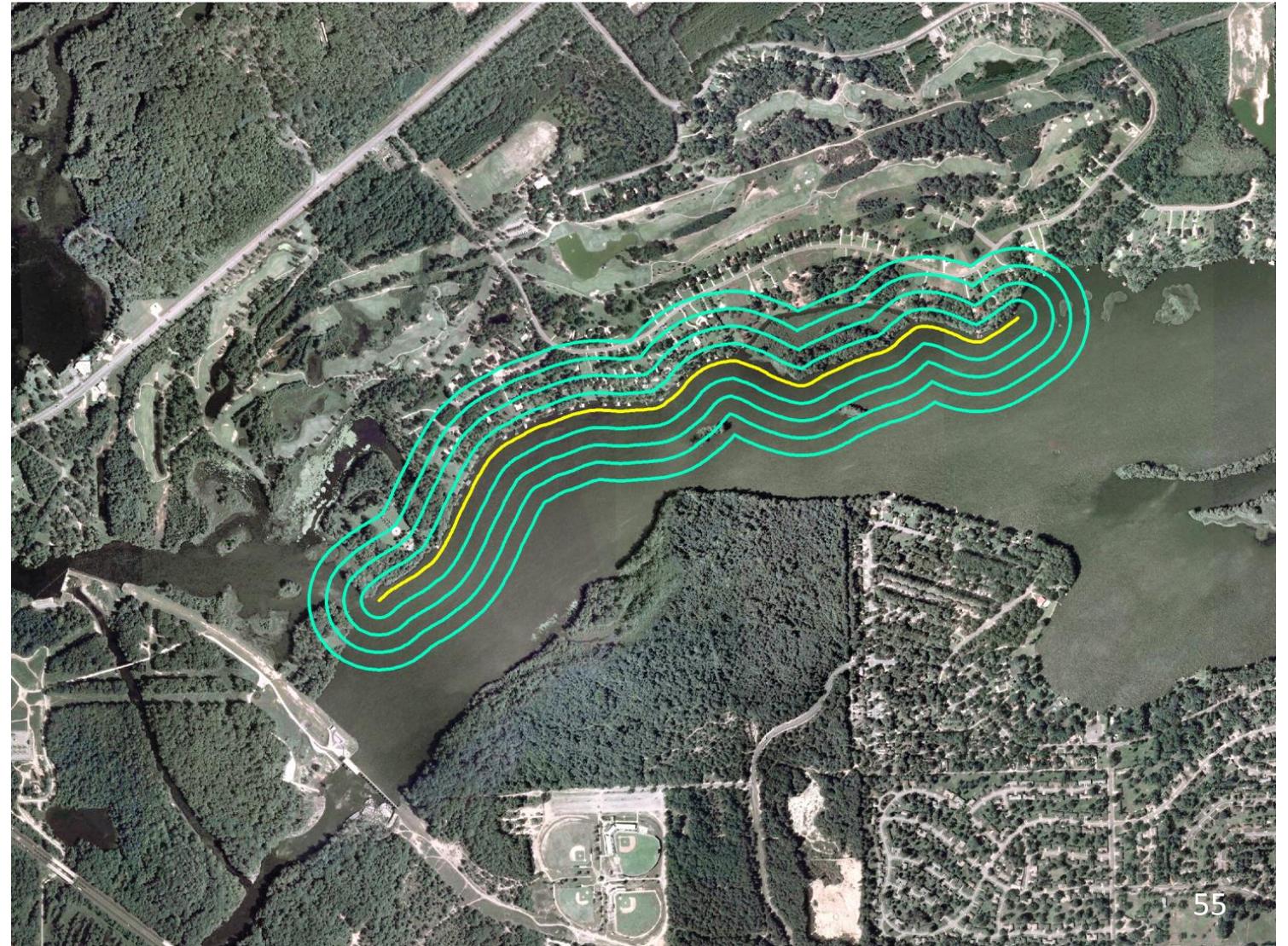
Parallel transects

Prior to a field survey, multiple parallel transects can be generated in a GIS and downloaded to a hand-held device to aid in field navigation. Here we have simply used a line that defined the margin of the reservoir to generate parallel transect lines at a specified distance that relates to the range setting selected for the survey.

Although more work needs to be done, all indications are that low-cost sonar habitat mapping can be successfully adapted to lentic environments. Substrates and features of interest will differ, thus providing an opportunity for the development and evaluation of new sonar applications specific to lentic environments. We hope some of you take up this challenge!

Transects for Open Water

- Create in GIS, download, and follow during survey



Where do we go from here

We are fortunate and grateful to have had the resources, support, and opportunities required to successfully accomplish many of the original objectives of the sonar habitat mapping initiative. We continue to offer training, and develop supporting materials, and now currently work toward the development and evaluation of new sonar mapping applications and applied studies, several of which are listed here. We hope that these studies continue to build the foundation necessary for widespread adoption and implementation of this promising methodology.

As always, please feel free to contact us with questions or comments, and provide feedback on your experiences with low-cost sonar habitat mapping. We would be glad to provide any assistance possible.

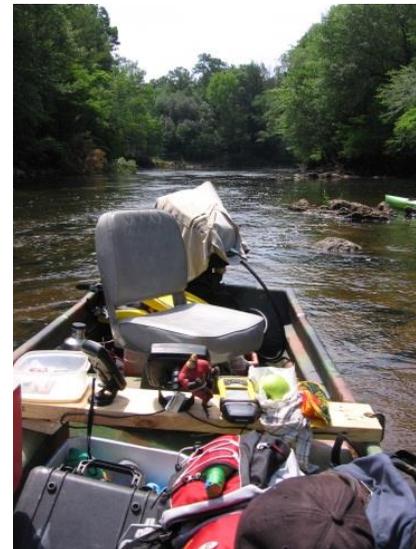
We hope that this Guidebook and the attendant materials successfully serve our stated purpose of providing you with a quick-start guide to low-cost sonar habitat mapping. Please share these materials with others, and may you find the enlightening experience of sonar mapping well within your grasp.

We'll leave you with just a few more photographs of our work on sonar mapping...Thanks to all of our field assistants, interns, and supporters!

The Future of the Initiative

Application studies/projects underway

- **Habitat selection of female Barbour's map turtle in a Southwest GA creek (S. Sterret, in preparation)**
- **Using time-lapse sonar habitat mapping to assess changes in substrate deposition following a 10-year flood event (A. Crawford, MS student)**
- **GA Altamaha Basin mapping project (sturgeon) (T. Litts/GADNR)**
- **Apalachicola River Applied Mapping project- modeling the distribution and abundance of mussels in a large, meandering river (R. Smit, MS student Auburn/USFWS)**
- **Development and evaluation of a sonar-based approach to monitoring distribution and abundance of adult Gulf sturgeon (A. Kaeser/USFWS)**
- **A performance evaluation of 2 side scan systems for detecting Gulf sturgeon (USFWS/USGS/NCState/Delaware State University)**
- **Evaluation of alligator snapping turtle habitat use in the Suwannee River via telemetry and sonar mapping (T. Thomas, FWC/U Florida, USFWS)**



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