

# Fisheries

VOL 33 NO 12  
DECEMBER 2008



Fish News  
Legislative Update  
Journal Highlights  
Calendar  
Job Center

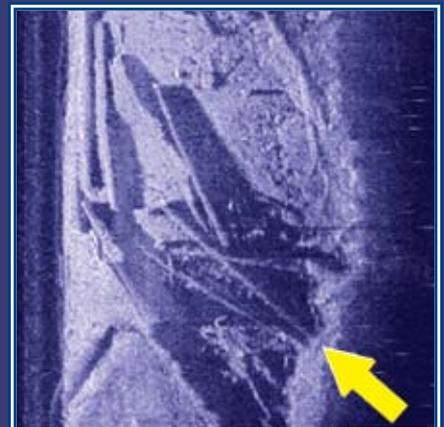
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**Assessment of  
Deadhead Logs and Large Woody Debris  
Using Side Scan Sonar and Field Surveys**

**Vertical Zoning in Marine Protected Areas**

**1962 Rotenone Treatment of  
the Green River, Wyoming and Utah,  
Revisited**



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AMERICAN FISHERIES SOCIETY • WWW.FISHERIES.ORG

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*William G. Franzin*

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*Robert W. Wiley*

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**COVER:** Cache of deadhead logs along Chickasawhatchee Creek during low water conditions (above) and as shown in side scan sonar imagery (below). In both images the arrow identifies the same log and the rocky left side and sandy right side areas are visible.

**CREDIT:** Adam Kaeser

## FEATURE: FISH HABITAT

# An Assessment of Deadhead Logs and Large Woody Debris Using Side Scan Sonar and Field Surveys in Streams of Southwest Georgia



**ABSTRACT:** Large woody debris provides essential habitat in sand-bed streams of the southeastern United States. In many Coastal Plain streams, pre-cut timber, lost more than a century ago during river transport, contributes to the extant large woody debris pool. The extraction of these logs, otherwise known as deadhead logging, threatens habitat integrity in these systems. Little is known of the distribution, abundance, and ecological value of deadhead logs, thus hindering attempts to manage and protect this resource. Moreover, the use of traditional field-based methods to inventory wood is slow and costly in large turbid streams. Our objectives were to assess wood at several sites in southwest Georgia using traditional methods, then use these data to evaluate the efficacy of quantifying wood using side scan sonar imagery. Deadhead logs were widely distributed and constituted a substantial proportion (> 50% volume and surface area) of the total large woody debris found at study sites. Given these findings, the wholesale removal of deadhead logs could largely impact the ecological integrity of such streams. Analyses revealed strong correlations ( $r^2 = 0.82 - 0.98$ ) between sonar wood estimates and actual counts suggesting that side scan sonar can be used as a rapid, inexpensive method to quantify wood throughout navigable systems.

**Adam J. Kaeser and  
Thomas L. Litts**

Kaeser is an aquatic ecologist and Litts is a GIS specialist with the Georgia Department of Natural Resources, Wildlife Resources Division. Kaeser can be contacted at [adam.kaeser@dnr.state.ga.us](mailto:adam.kaeser@dnr.state.ga.us).

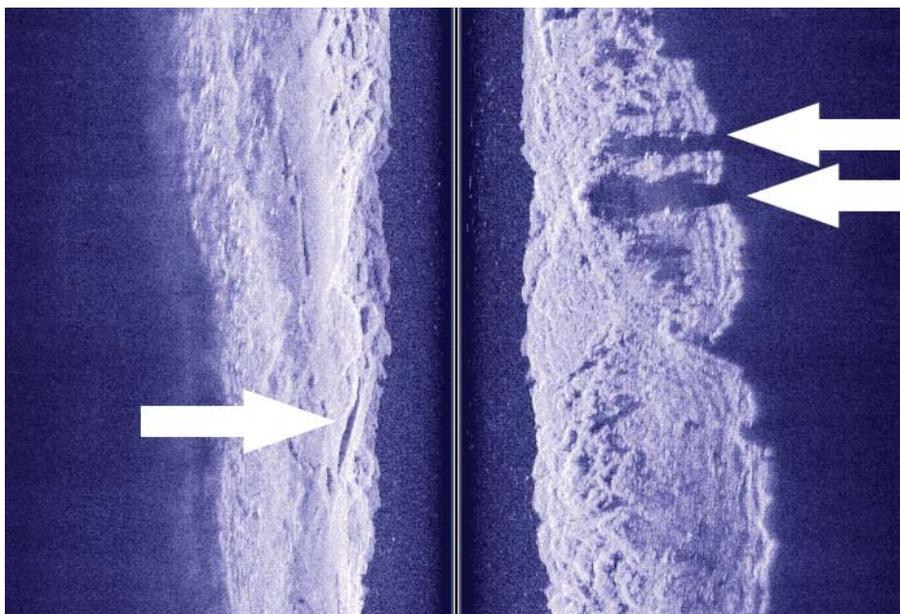
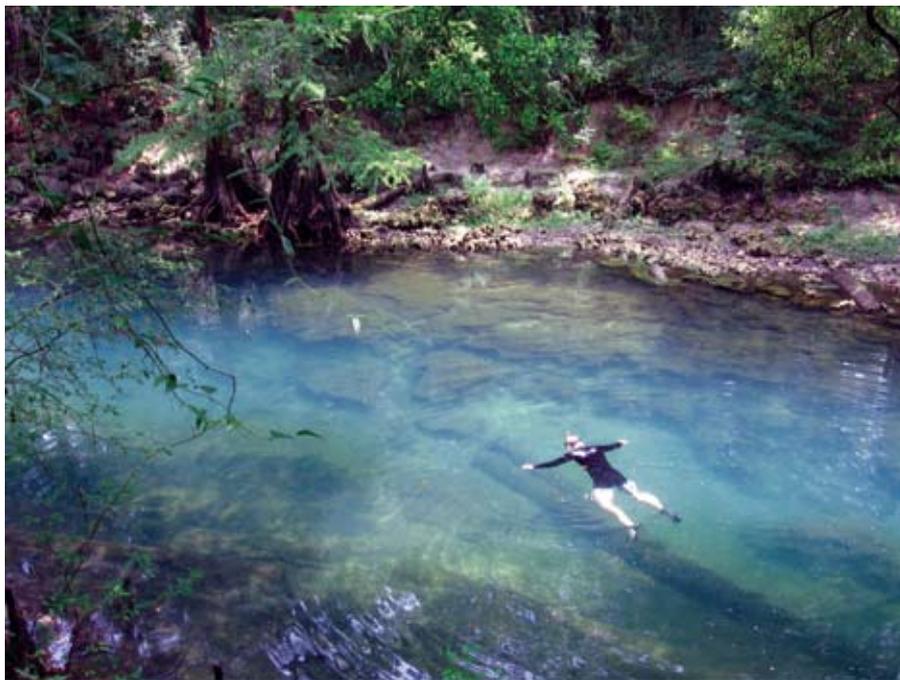
## Evaluación de los troncos muertos y escombros de madera en ríos del suroeste de Georgia, mediante el uso de sonar y estudios de campo

**RESUMEN:** Los escombros de madera proveen un hábitat esencial en los ríos de fondo arenoso del sureste de los Estados Unidos de Norteamérica. En varios ríos de las planicies costeras, la madera pre-cortada, perdida hace más de un siglo por el transporte de los ríos, contribuye de manera importante al suministro existente de escombros de madera. La extracción de estos troncos amenaza la integridad del hábitat en dichos sistemas. Poco se conoce acerca de la distribución, abundancia y valor ecológico de los troncos muertos, lo cual dificulta el manejo y protección de este recurso. Los métodos de campo tradicionales para hacer inventarios de la madera son tardados y costosos, en especial en grandes ríos de alta turbidez. Nuestros objetivos fueron evaluar los escombros de madera en distintos sitios del suroeste de Georgia mediante métodos tradicionales, y posteriormente utilizar estos datos para evaluar la eficacia de las imágenes de sonar para cuantificar la misma variable. Los troncos muertos se observaron ampliamente distribuidos y constituyeron una proporción significativa (> 50% del volumen y superficie) del total de escombros de madera en los sitios de estudio. Dados estos hallazgos, la remoción extensiva de troncos muertos podría impactar considerablemente la integridad ecológica de esos ríos. Los análisis mostraron altas correlaciones ( $r^2 = 0.82 - 0.98$ ) entre las estimaciones de la cantidad de escombros provenientes de imágenes de sonar y de censos directos, lo que sugiere que el sonar puede utilizarse como un método rápido y relativamente barato para cuantificar los escombros de madera a lo largo de sistemas navegables.

### INTRODUCTION

Wood performs many important ecological functions in lotic systems. Woody debris enhances habitat and hydraulic complexity (Montgomery et al. 2003; Mutz 2003), provides a stable substrate for primary and secondary production (Wallace and Benke 1984; Benke et al. 1984; Benke 2001; Benke and Wallace 2003), traps and retains organic matter (Raikow et al. 1995; Webster et al. 1995), provides cover and refuge for a myriad number of migratory and resident stream organisms (Dolloff and Warren 2003; Gregory et al. 2003; Gagnon et al. 2006), and mediates channel forming processes such as sediment transport and deposition (Cobb and Kaufman 1993; Montgomery et al. 2003). The ecological benefits of wood are particularly important in sand-bed streams of the Coastal Plain physiographic province of the southeastern United States (Wallace and Benke 1984; Benke et al. 1984, 1985; Smock et al. 1985; Felley 1992; Benke and Wallace 2003; Dolloff and Warren 2003).

Since European settlement, landscapes and riverine habitats have been dramatically altered through logging and in-stream woody debris removal in Georgia (Mueller 1990; Benke 2001) and throughout the Southeast (Felley 1992). During the late 1800s through early 1900s logged trees, specifically Southern longleaf pine (*Pinus palustris*) and bald cypress (*Taxodium distichum*), were floated and rafted down Georgia waterways (Morrison 1970; Tripp



Snorkeling to count large woody debris. Joshua Hubbell floats above a large deadhead log (in sonar image on left white arrow points to log).

Two cypress trees on the far bank appear in the sonar image casting shadows (white arrows on right image), and a limestone bedrock outcropping appears textured relative to the smooth sandy substrate along the near bank.

provides high-resolution imagery of river bottom features revealing objects such as rocks and logs. In contrast to the expensive (\$70,000+) side scan sonar devices commonly used in marine and lacustrine environments, the Humminbird® systems are inexpensive (~\$2,000) and can be mounted on a small boat, thus facilitating surveys in shallow, rocky streams.

Deadhead log removal poses a real threat to habitat integrity in Coastal Plain streams. Florida instituted a DHL program in 2000 and has since issued permits for log removal. Logging reports indicate that > 16,000 logs have been removed since 2000; however, due to potential unregulated activity and underreporting, this number may be conservative (Sara Merritt, Florida Department of Environmental Protection, pers. comm.). Georgia recently established a 2-year DHL program and other states (e.g., Alabama) have received inquiries regarding the establishment of similar programs. Given the finite nature of the resource, dwindling supplies in one region may increase pressure to permit logging or increase unregulated logging in other regions.

Despite their size, permanence, and potential ecological significance, DHL distribution and abundance is poorly documented, impeding the management, valuation, and conservation of this resource. Because several factors including water depth, clarity, and expense pose logistical barriers to conventional survey techniques, we evaluated a promising alternative that employs a Humminbird® 900-series side imaging system to rapidly and inexpensively detect and map sunken logs and large woody debris (LWD). In this study a piece of wood with diameter  $\geq 10$  cm and length  $\geq 1.5$  m was recognized as LWD. Our objectives were (1) to assess the distribution, abundance, and relative contribution of DHLs to the overall woody debris pool in two streams in Southwest Georgia, (2) to compare the characteristics of DHLs and LWD, and (3) to evaluate the ability to identify DHL caches and quantify total large woody debris (TLWD) using side scan sonar in these systems as compared to conventional means.

## METHODS

### Study areas

Two streams in Georgia were examined during this study, Ichawaynochaway Creek (IC) and Chickasawhatchee Creek (CC) (Figure 1). Both streams are low-gradient

1983). During transport many logs sank or became lodged in banks, bars, and rocky shoals. These so-called sinker or deadhead logs (DHLs) were abandoned and became permanent components of stream ecosystems. Although forestry practices have changed and log rafting is no longer practiced, wood removal from streams still occurs, often by citizens seeking an unobstructed passage or view of the river (A. Kaeser, pers. obs.).

Removal of DHLs has occurred for many years in many regions of the United States because of the high market value of this wood, spawning an industry ranging from "cottage" to highly organized companies (Cayford and Scott 1964; Russell 1997; Hurst 2005). Traditionally, divers and probes were used to locate DHLs. Today, technologically advanced tools like the Humminbird® 900-series side imaging (SI) system are available. This device

(< 0.001% slope) tributaries to the lower Flint River located within the Gulf Coastal Plain of southwestern Georgia. Detailed geographic and hydrologic descriptions for both may be found in Golladay and Battle (2002) and Golladay et al. (2004). These streams were selected because higher discharges during the wet season (winter-spring) permit boat navigation, low flows during summer permit wading and snorkeling for ground truth surveys, and both streams contained submerged DHLs.

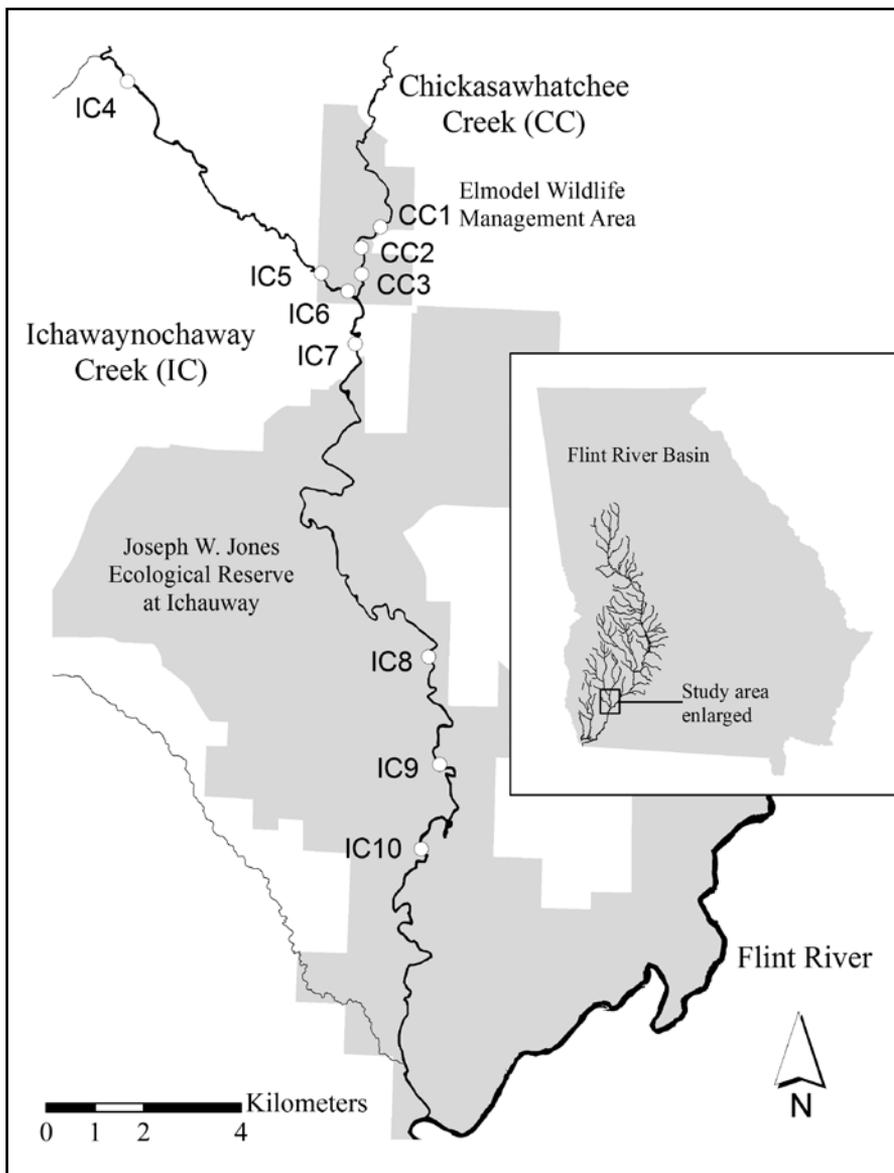
Ten 460–700 m long reaches were randomly selected from areas located within 3 km of an existing boat landing. Geographic coordinates of reach boundaries were obtained in the field with a Wide Area Augmentation System (WAAS) enabled Garmin GPSMAP® 76 Global Positioning System (GPS) unit, and flagged for future reference. All study reaches exhibited well-defined stream channels comprising sandy runs, shallow rocky shoals, and portions incised into Ocala limestone bedrock. The upper reaches along Ichawaynochaway and Chickasawhatchee creeks (4<sup>th</sup> order) were located in or near the Elmodel Wildlife Management Area (WMA; Figure 1). The lower reaches along Ichawaynochaway Creek (5<sup>th</sup> order) were located within the 11,500 ha Ichauway Ecological Reserve. Within these two properties, streamside riparian areas were largely intact. Human modification of the stream channel and the removal of woody debris were assumed to be minimal to nonexistent in recent decades, although cattle access at portions of Chickasawhatchee Creek occurred until 1996 when Elmodel WMA was purchased by the state of Georgia. Reaches IC4 and IC7 contained portions of streamside forest buffer that had been cleared for agricultural purposes. In these areas some bank erosion was evident.

**Procedures used to assess submerged wood**

**(a) Acquiring sonar imagery**

We employed a Humminbird® 981c SI system to capture sonar imagery at all study reaches (except IC4 due to restricted boat access) during high water conditions in winter-spring 2007 (Table 1). High flows were targeted in order to image the entire bankfull stream channel. The SI system was connected to the Garmin GPSMAP® 76 GPS to provide coordinate information for image capture locations, at a stated accuracy of 3–5 meters (Garmin 2006). The sonar transducer was aft-mounted to the port side of a johnboat transom, and its frequency set

**Figure 1.** Location of survey sites in southwest Georgia.



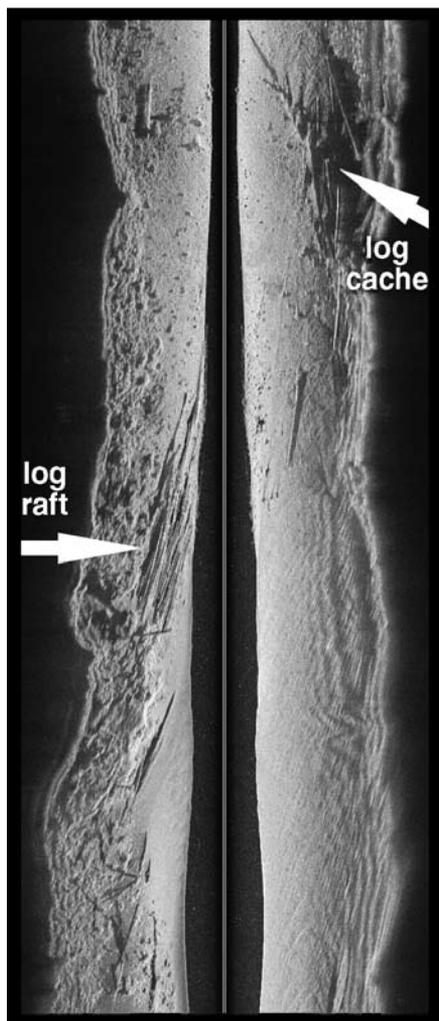
**Table 1.** Wood composition observed in study reaches. Large woody debris (LWD) is any piece of wood with diameter ≥ 10 cm and length ≥ 1.5 m not classified as pre-cut submerged timber. Deadhead logs (DHLs) are all pieces of LWD classified as pre-cut submerged timber. Total large woody debris (TLWD) is the sum of all LWD and DHLs found in each reach.

Stream reach ID	Date of sonar survey	LWD		DHL		DHL as % of TLWD
		pcs/ha	pcs/100m	logs/ha	logs/100m	
CC 1	2/12/07	143	27	16	3	10
CC 2	2/12/07	168	28	28	5	14
CC 3	2/12/07	139	26	76	14	35
IC 4	-	85	26	3	1	3
IC 5	2/12/07	114	38	18	6	13
IC 6	2/12/07	105	38	39	14	27
IC 7	2/12/07	91	33	61	22	40
IC 8	4/6/07	84	24	21	6	20
IC 9	4/6/07	119	37	13	4	10
IC 10	4/2/07	76	30	42	16	36
<b>mean</b>		<b>112</b>	<b>31</b>	<b>32</b>	<b>9</b>	
<b>95% C.I.</b>		<b>91-134</b>	<b>27-35</b>	<b>15-48</b>	<b>4-14</b>	

at 455 kHz during sonar surveys. The sonar range was set to 65 feet during the survey of Chickasawhatchee Creek and 80 feet during the survey of Ichawaynochaway Creek. Coordinate data and sonar images were simultaneously recorded to the SI system during the survey. These data were recorded at regular intervals such that consecutive overlapping images were acquired. Prior to the surveys, targeting exercises were conducted with a piece of PVC pipe (length 1.7 m, diameter 11 cm) submerged in various locations to evaluate our ability to image LWD-like objects.

**(b) Interpretation of sonar imagery to identify wood**

**Figure 2.** Sonar mosaic of a stream reach revealing, at this scale, the remains of a raft of deadhead logs (middle left), a second cache of logs (upper right), and several additional logs and pieces of large woody debris. (This imagery obtained with a front-mounted transducer).



Using Microsoft (MS) PowerPoint, we spliced overlapping sonar images together to produce a seamless mosaic for each study reach. Image mosaics were first reviewed to identify any areas that appeared to contain a cache of DHLs, defined in this study as any area that contained  $\geq 10$  DHLs within a 20-m radius (Figure 2). During image review, DHLs were identified as large, symmetrical, non-branching, cylindrical objects. Sonar mosaics were then examined independently by two reviewers to obtain estimates of TLWD, defined as the sum of all DHLs and LWD. Targeting exercises and field experience indicated that all pieces of wood evident in our sonar images would likely qualify as TLWD.

**(c) Ground truth survey**

Ground truth surveys of all reaches were conducted during low water conditions in summer 2007. Shallow areas were waded and snorkeled, whereas deeper areas were surveyed with a 3-person scuba diving crew. Reaches were subdivided into contiguous 10-m segments in Chickasawhatchee Creek, and 20-m segments in Ichawaynochaway Creek, as a manageable area of channel within which to tally TLWD. During the analysis of wood distribution, wood counts from adjacent 10-m segments in Chickasawhatchee Creek were combined to represent wood occurring in 20-m segments.

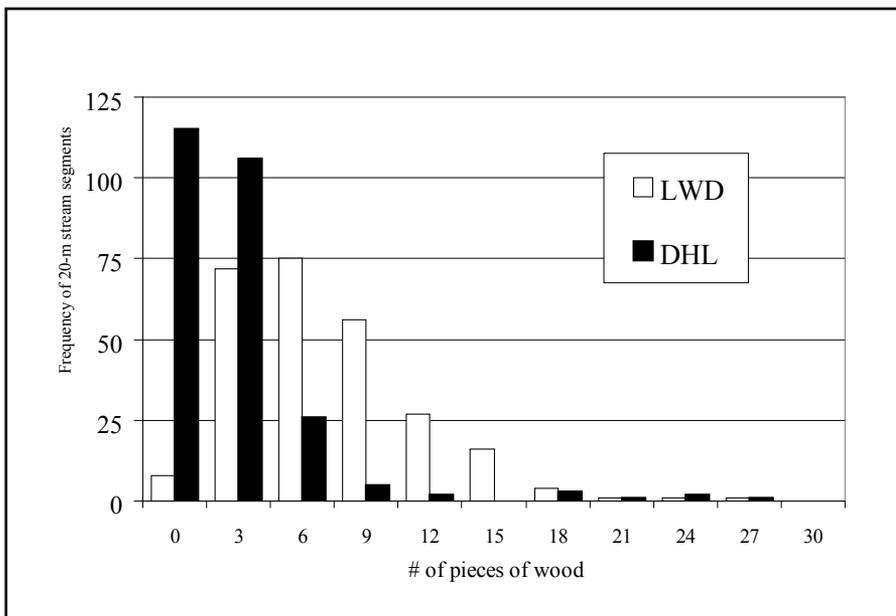
To estimate reach area we measured bank-full channel width using a tape or Nikon ProStaff Laser 440 rangefinder at each segment boundary. Deadhead logs were distinguished from other woody debris as logs that exhibited ax-cut or sawn, straight-cut ends in combination with densely spaced growth rings characteristic of old-growth timber. Some DHLs also exhibited the scarring or "cat-face" pattern as a result of past turpentine activities.

During the ground truth survey of reaches IC5, IC6, CC2, and CC3 we sampled DHLs and LWD in wadeable areas to estimate wood volume and surface area. For each piece of wood, we recorded end circumferences and length for that portion qualifying as TLWD. We estimated volume and surface area assuming that each piece of wood was a perfect cylinder. Volume and surface area differences between DHLs and LWD were analyzed using two sample t-tests performed in MS Excel. Using these values, and the actual quantities of LWD and DHLs observed in study reaches, we calculated an estimate of total wood volume and surface area in Chickasawhatchee and Ichawaynochaway creeks.

**(d) Analysis of sonar data**

The accuracy of sonar wood count estimates of TLWD from both reviewers was assessed with wood counts obtained during

**Figure 3.** Frequency distribution of 20-m stream segments containing varying quantities of wood classified as large woody debris or deadhead logs. (LWD = large woody debris, i.e. all pieces of wood with diameter  $\geq 10$  cm and length  $\geq 1.5$  m not recognized as pre-cut submerged timber, and DHL = deadhead logs, i.e. all pre-cut submerged timber).



ground truth surveys. The statistical relationships between sonar-based and field-based counts of TLWD were examined with regression analysis (MS Excel). Separate regressions were performed on the counts from each reviewer and each stream. Data from the three Chickasawhatchee Creek and six Ichawaynochaway Creek reaches were analyzed separately because different range settings had been used during image acquisition, and targeting revealed that the range setting influenced our ability to resolve LWD.

## RESULTS

### Distribution and Abundance of Wood from Ground Truth Surveys

We completed surveys of 5.22 km (15.37 ha) of linear stream channel during the study. Reaches contained similar quantities of LWD (mean: 31 pieces/100m, 95% C.I. 27–35 pcs/100 m), and nearly all stream segments (97%) contained some LWD (Figure

3). The pool of TLWD varied from 27–55 pcs/100 m among study reaches; DHLs accounted for 3–40% of TLWD (Table 1).

Deadhead logs were found in all study reaches and ranged in abundance from a low of 1 log/100m (IC 4) to 22 logs/100m (IC7). Deadhead logs were also widely distributed within reaches; more than half (56%) of all 20-m segments contained one or more DHLs. Overall, DHLs constituted 21% of TLWD observed in Chickasawhatchee Creek and 24% of TLWD in Ichawaynochaway Creek.

### Wood Volume and Surface Area

The mean volume of a DHL was significantly greater (mean volume = 1.08 m<sup>3</sup>, SD = 1.12) than the mean volume of a piece of LWD (mean = 0.187 m<sup>3</sup>, SD = 0.190; 2 sample t-test,  $p < 0.001$ ; Figure 4). Likewise, the mean surface area of a DHL (mean = 10.26 m<sup>2</sup>, SD = 6.66) was significantly greater than the surface area of a piece of LWD (mean = 2.97 m<sup>2</sup>, SD = 2.27; 2 sam-

ple t-test,  $p < 0.001$ ). Chickasawhatchee and Ichawaynochaway creeks channel areas exhibited similar estimates of wood volume and surface area (Table 2). Despite the numerical predominance of LWD, DHLs constituted > 50% of the total volume and ~50% the total surface area of TLWD in both Chickasawhatchee and Ichawaynochaway creeks.

### Sonar Assessment of Wood

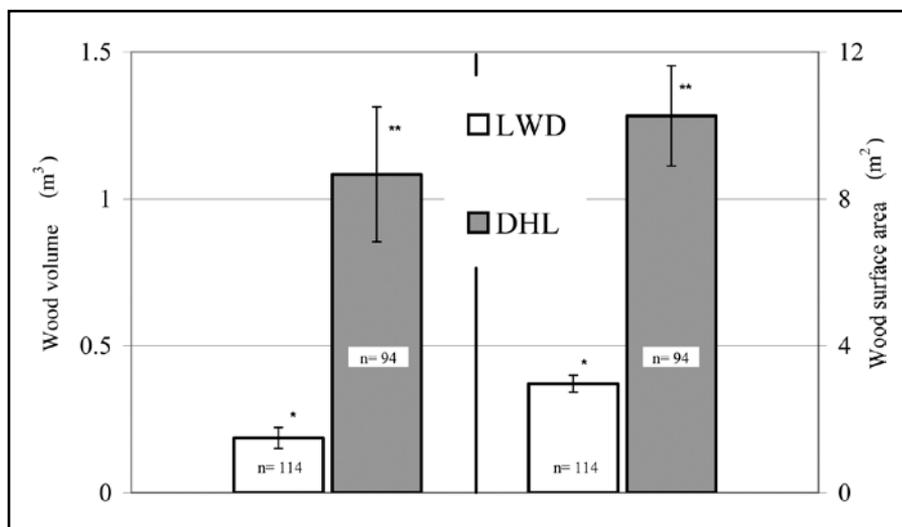
Several DHL caches were identified during field surveys; nine 20-m segments contained a log cache. Four of these log caches were located in Chickasawhatchee Creek and 5 log caches were found in Ichawaynochaway Creek. Of these 9 cache locations, 6 (67%) had been identified prior to ground truth surveys through inspection of side scan sonar imagery.

Both reviewers consistently underestimated the actual quantity of TLWD present in reaches through interpretation of sonar imagery. The mean percent error of sonar wood estimates by Reviewer AK was 49% (range 22–66%) and the mean percent error of estimates by Reviewer TL was 53% (range 9–72%). Sonar estimates were, however, highly correlated with actual wood counts obtained during ground truth surveys (Figures 5, 6). Sonar wood estimates by Reviewers AK and TL explained 87% and 82% ( $r^2$  values), respectively, of the variation in actual wood counts observed in Ichawaynochaway Creek. In Chickasawhatchee Creek, sonar wood estimates by Reviewers AK and TL explained 98% and 85% ( $r^2$  values) of the variation in actual wood counts.

### Time Expenditures

Detailed time expenditure records were kept for sonar and field-based surveys, data preparation, and sonar image interpretation. On average, 29 man-hrs/km were

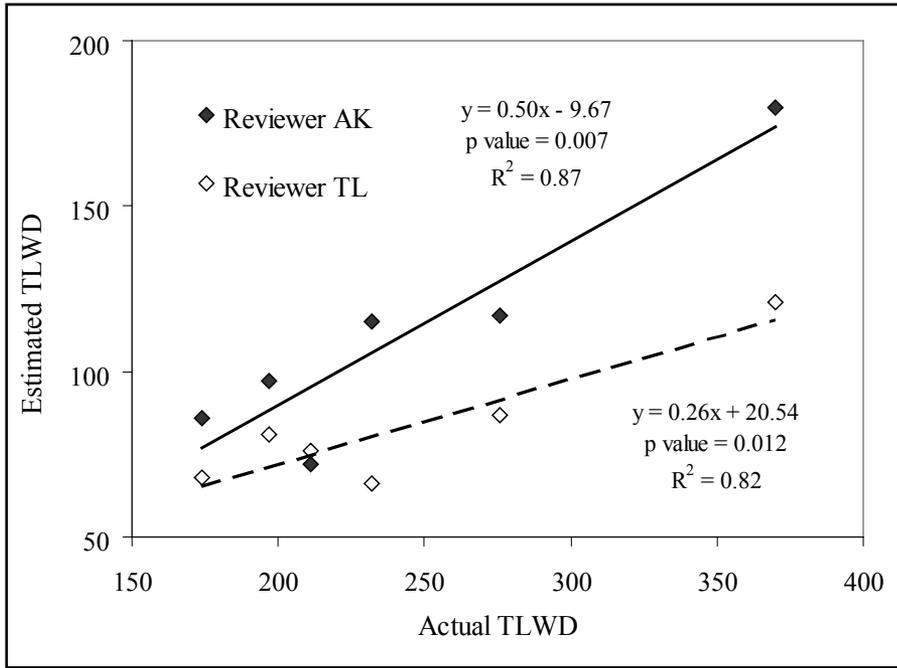
**Figure 4.** Mean wood volume (left side of chart) and surface area (right side) of large woody debris (LWD) and deadhead logs (DHL) encountered in study reaches located within the Elmodel Wildlife Management Area. Error bars represent 95% confidence intervals. Values followed by different numbers of asterisks are significantly different using a 2-sample t-test ( $p < 0.001$ ).



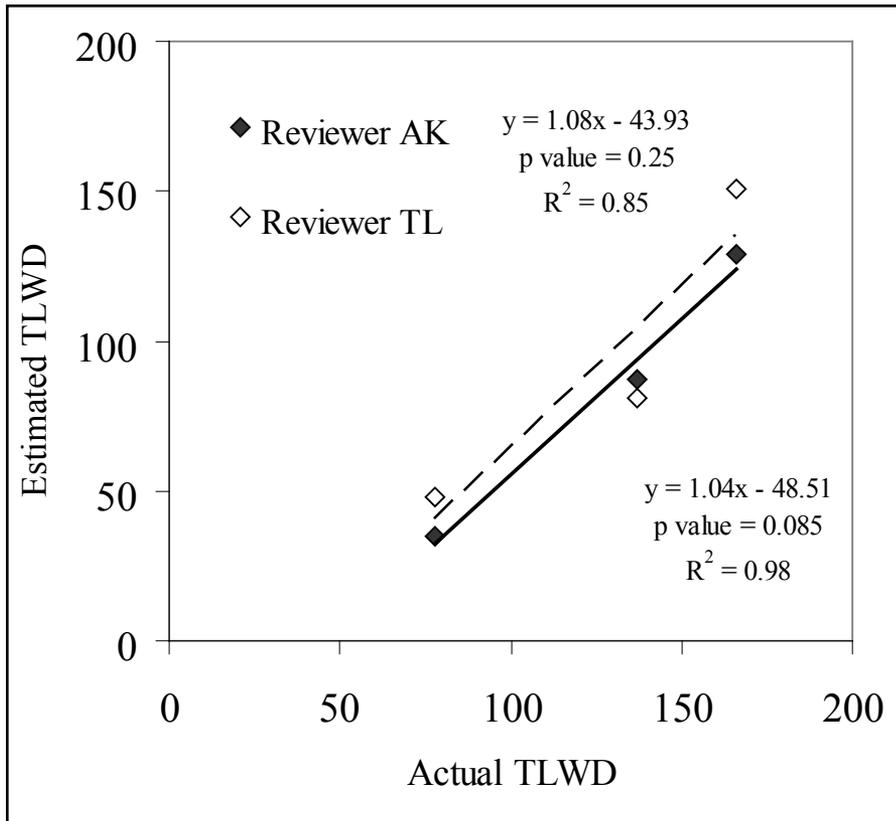
**Table 2.** Wood volume and surface area in Chickasawhatchee Creek and Ichawaynochaway Creek, based on the total quantity of large woody debris (LWD) and deadhead logs (DHL) observed in each stream and mean volume and surface area estimates for each wood class.

Stream	Total length surveyed (m)	Total area surveyed (ha)	Wood volume (m <sup>3</sup> )/linear m of stream			Wood volume (m <sup>3</sup> )/ha			Wood surface area (m <sup>2</sup> )/linear m of stream			Wood surface area (m <sup>2</sup> )/ha		
			LWD	DHL	total	LWD	DHL	total	LWD	DHL	total	LWD	DHL	total
Chickasawhatchee Creek	1500	2.73	0.051	0.079	0.130	27.9	43.3	71.2	0.807	0.745	1.55	443	410	853
Ichawaynochaway Creek	3770	12.65	0.061	0.108	0.169	18.0	32.3	50.3	0.960	1.03	1.99	286	306	592
<b>Average</b>			<b>0.056</b>	<b>0.094</b>	<b>0.150</b>	<b>23.0</b>	<b>37.8</b>	<b>60.8</b>	<b>0.884</b>	<b>0.888</b>	<b>1.77</b>	<b>365</b>	<b>358</b>	<b>723</b>

**Figure 5.** Estimated counts of total large woody debris (TLWD) from sonar imagery versus actual counts obtained during ground-truth surveys of Ichawaynochaway Creek reaches IC5-IC10. Imagery was reviewed by the authors A. Kaeser (AK- solid trendline) and T. Litts (TL- dashed trendline).



**Figure 6.** Estimated counts of total large woody debris (TLWD) from sonar imagery versus actual counts obtained during ground-truth surveys of Chickasawhatsee Creek reaches CC1-CC3. Imagery was reviewed by the authors A. Kaeser (AK- solid trendline) and T. Litts (TL- dashed trendline).



spent conducting field surveys of TLWD. In contrast, the sonar-based approach required an average 2.5 man-hrs/km to complete as follows: 14 min/km to capture sonar imagery on the water, 63 min/km to prepare image mosaics, and 75 min/km to interpret imagery.

## DISCUSSION

### Composition of Large Woody Debris

The ecological importance of LWD in streams of the southeastern Coastal Plain is often noted, yet few studies have rigorously examined the composition of the debris pool. Our surveys revealed an abundance of LWD and DHLs throughout study areas. Although LWD predominated, DHLs contributed substantial volume and surface area to the extant woody debris pool. Our findings indicate that DHLs constitute an important component of TLWD in streams of Southwest Georgia, and, presumably, other streams in the southeastern Coastal Plain.

Some important distinctions exist between DHLs and other woody debris. Many of the ecological benefits attributed to woody debris, such as providing stable habitat for stream organisms (Angermeier and Karr 1984; Benke and Wallace 2003; Sass et al. 2006), and contribution to hydraulic complexity and channel forming processes (Mutz 2003; Peigay 2003; Daniels and Rhoads 2007), are influenced by the size, stability, and longevity of the piece of wood (Gurnell 2003). Many of the largest pieces of wood encountered during our study were DHLs. Their massive size not only contributes a large surface area for invertebrate production and cover, but also physically anchors them in place, conferring long-term habitat stability and mechanical influence. Given the low stream power associated with these streams, DHLs are unlikely to move during high discharges, and may not move at all except perhaps during the most extreme floods. The persistence of several intact rafts of logs encountered during surveys further alludes to the long-term stability of submerged logs.

In addition to size and spatial stability, the longevity of DHLs is exceptional. The heavy resin content of longleaf pine and cypress, and conifers in general, combined with anaerobic conditions within submerged and/or buried wood restrict the colonization of microbes and gallery forming invertebrates, thereby preserving logs from decay (Harmon et al. 1986; Bilby 2003). Larger

wood stems have been shown to decay slower than smaller stems (Harmon et al. 1986), thus the massive bole size of DHLs also aids preservation. Testament to their slow decay, Florida loggers have even recovered logs exhibiting superficial brands made by logging companies to distinguish their property from others (Sara Merritt, Florida Department of Environmental Protection, pers. comm.). Given that the period of timber production in southwest Georgia occurred during the late 1800s through early 1900s, it is likely the DHLs we encountered recruited to streams during this period. Although DHLs are not the most structurally complex form of LWD, DHLs will likely outlast most other LWD.

### **Sonar Assessment of Wood**

Most DHL caches were identified using side scan sonar. The existence of log caches and the ability to quickly locate them pose a real threat to this resource. Simply put—log caches are the first to be discovered and mined. During the first year of the Florida logging program, loggers removed 1/3 of the total reported harvest for the last 8 years (5,708 of 16,365 logs; Sara Merritt, Florida Department of Environmental Protection, pers. comm.). Therefore, the institution of even a temporary program to permit the harvest of DHLs from state waters could result in the loss of much habitat. Conversely, resource managers can employ side scan sonar to document and monitor DHLs, a critical first step towards the valuation and protection of these aquatic resources.

This study is the first of its kind to examine the use of the Humminbird® SI system for assessment of TLWD; other side scan devices have been tested for such purposes (e.g., Quinn et al. 2005). Although sonar estimates could only account for up to 80% of the TLWD pool, the high correlations between sonar estimates and actual wood abundances indicates that the method is precise in estimating TLWD at the riverine scale. Therefore, as a rapid and reliable index, side scan sonar can offer a cost-effective assessment tool.

We identified several factors affecting the accuracy of sonar estimates and ability to identify log caches. Mounting the transducer behind the boat produced visually degraded imagery to one side of the boat's path, apparently due to propeller turbulence. We later experimented with front mounting, which greatly improved image quality (e.g., see Figure 2). In addition, orientation and size of submerged woody debris affected

our ability to estimate TLWD based on targeting exercises with the PVC LWD analog. Wood pieces oriented perpendicularly to the boat path were sometimes poorly imaged, and we suspect that sonar also failed to reveal some small LWD pieces. A large proportion of the LWD encountered during the study was in fact small and near the threshold dimensions of LWD. Therefore, adjusting transducer placement may improve the overall accuracy of wood counts, yet it seems unlikely that sonar will image all existing LWD due to factors such as size and orientation.

We do not believe that TLWD redistribution was a factor affecting the accuracy of sonar estimates. Few higher flows, no flood events, and a prolonged period of summer low flow conditions occurred in between sonar surveys and ground truth surveys during this study. The low stream power associated with these systems makes it unlikely that TLWD was moved during this period. The fact that ~88% of the variation associated with sonar estimates can be explained by actual wood counts further argues that wood redistribution was negligible. Unless higher flows redistributed wood evenly among study reaches, it seems unlikely we would encounter a spurious correlation between sonar estimates and field counts.

### **Recommendations for Sonar Wood Surveys**

We recommend that SI system settings, particularly the sonar beam range, stream conditions (e.g., discharge), and boat speed remain constant, inasmuch as possible, during sonar wood surveys. Targeting pre-positioned objects during surveys provides a means to assess the effectiveness of imaging under ambient conditions, and provides a standard by which to classify objects observed in imagery. Following image acquisition, we recommend interpreting TLWD from all imagery at one time. We feel this approach maintained consistency and improved the precision of our wood estimates. Sonar counts alone may be insufficient to accurately quantify wood, therefore we suggest that ground truth surveys in carefully selected reaches are a wise investment of time. As demonstrated in this study, ground truth data can be used to calibrate sonar wood estimates to reflect actual distribution and abundance of TLWD throughout a system.

## **SUMMARY**

This study is the first to reveal that DHLs are widely distributed and substantially contribute to the total quantity, volume, and surface area of TLWD present in streams of Southwest Georgia. Although no studies have examined the ecological consequences of removing DHLs, it stands to reason that the removal of 50% of the extant volume and surface area of wood in a stream is likely to measurably impact the ecological integrity of an aquatic system. In future field studies, we recommend that researchers distinguish DHLs from other woody debris, and suggest that consideration be given to the ecological role of DHLs.

Benke and Wallace (2003) briefly discussed three techniques available for the assessment of LWD in streams: complete census, line-intersect estimation, and examination of aerial photographs. We propose that side scan sonar represents a promising, alternative technique for the rapid assessment of TLWD in navigable lotic and lentic waterways. Side scan sonar facilitates wood surveys across broad aquatic landscapes, enabling the examination of factors affecting the spatial and temporal patterns of wood distribution, and ecological associations (e.g., patterns of stream productivity), in ways deemed logistically unfeasible in the past. The applications of side scan sonar for mapping stream habitat extend well beyond woody debris. Our current work with the Humminbird® SI system includes GIS applications such as image geotransformation and mapping of stream substrates, topics we intend to present in forthcoming manuscripts. We hope that this research encourages scientists and managers to consider mapping, monitoring, and assessing stream habitat with low-cost side scan sonar, and suggest that future research evaluate the use of side scan sonar elsewhere to explore the effective boundaries of this remote sensing technique.

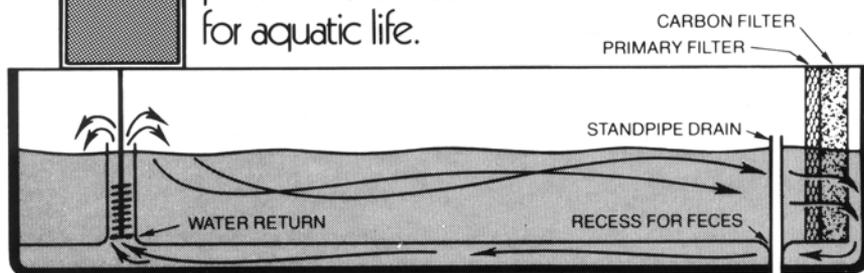
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