DETECTING SUBMERGED REMAINS: CONTROLLED RESEARCH USING SIDE-SCAN SONAR TO DETECT PROXY CADAVERS

by

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ABSTRACT

While side-scan sonar has become a valuable geophysical tool for forensic water searches, controlled research is paramount to determine the best practices for searches in aquatic environments as it provides a structured environment in which to investigate variables that influence the effectiveness of the technology and provides valuable experience for sonar operators. The purpose of this research is to conduct controlled research in order to evaluate the applicability of side-scan sonar to searches involving submerged firearms and proxy cadavers. In addition, the best practices for employing this technology in forensic searches in freshwater ponds and lakes in a humid, subtropical environment in Central Florida would be developed. Five street-level firearms were submerged in a pond, and two sets of three pig carcasses (*Sus scrofa*), utilized as proxies for human bodies, were staked to the bottom of a pond for this research. Transects were conducted over the firearms and the pig carcasses utilizing side-scan sonar. The first set of pig carcasses represented a child size (30-32 kg) and the second set a small adult size (51-54 kg). Results show that firearms were not detected due to the terrain and small size. However, this technology successfully located small to medium-sized proxy carcasses on a flat, sandy lake bottom when experienced operators were conducting the search. Conversely, vegetation obscured submerged bodies. While the smaller carcasses were difficult to detect throughout the data collection, medium-sized carcasses were easily discerned. Moreover, the medium-sized carcasses decomposed at the same rate as previous studies and were visible throughout each stage of decomposition. Finally, employing a 900 kHz frequency with a 20 m swath-width provided the best search parameters. Therefore, in the appropriate conditions,

side-scan sonar is an effective tool for locating submerged bodies in freshwater lakes and ponds in a humid, subtropical environment.

I would like to dedicate this thesis to Byron for teaching me a sense of accomplishment, and to Georgia for putting up with me during this process.

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CHAPTER ONE: INTRODUCTION

Geophysical tools are frequently used to locate clandestine graves in the terrestrial environment because they conserve the time and resources of investigating agencies and they are non-invasive (France et al., 1992; France et al., 1997; Schultz et al., 2006; Schultz, 2007; Schultz and Dupras, 2008; Schultz, 2008; Dupras et al., 2011). However, law enforcement agencies are increasingly transitioning these tools to aquatic environments to locate submerged bodies and forensic evidence. In aquatic environments, geophysical tools have additional benefits, such as decreasing the risk to divers, allowing searches to continue after nightfall or in poor visibility, and decreasing the sediment disturbance. While ground penetrating radar can be used in water environments, side-scan sonar is the geophysical tool gaining popularity due to its ease of use and high resolution images. As more law enforcement agencies incorporate this technology to their protocol for searches involving submerged bodies and evidence, a thorough understanding of the variables that influence detection are necessary.

There are a number of considerations when choosing the best geophysical method. One of the first aspects to consider is the material of the targets. Each geophysical tool detects specific materials, and these technologies often detect the contrast of the materials from surrounding objects. Hence, an understanding of the composition of the item will aid in the selection of the appropriate geophysical tool. Moreover, the size and morphology of the target must be considered. Smaller items may not be detected by geophysical tools, and flat objects may not be discernible from the bottom surface. The final consideration is the method of transmission. Passive tools only receive signals, while active tools can send or receive signals

(Dupras et al., 2011). Sonar can be passive, which is more commonly used for military applications, or active, which is more commonly used for scientific applications. Side-scan sonar is a form of active sonar (Newton and Stefanon, 1975; Fish and Carr, 1990; Lurton, 2002; Atherton, 2011).

To select the most appropriate method for a forensic water search, the different water search tools must be evaluated, compared, and contrasted. Therefore, it is important to provide an overview of the basic water search methods. Dive team searches, cadaver dogs, metal detectors, magnetometers, ground-penetrating radar, and side-scan sonar are all search techniques that can be employed in a forensic water search. Side-scan sonar is gaining popularity over other search methods for the initial search. However, to understand the advantages of side-scan sonar, the advantages and disadvantages of other search methods must be discussed. Table 1 summarizes the advantages and disadvantages of each technique.

Water Searches

Diver Team Searches

One of the most frequently utilized methods to search for submerged remains involves divers. Dive team searches require less expensive equipment and can be deployed relatively quickly. A variety of searches can be utilized based on the underwater terrain and the missing item (Becker, 1995; Bowens, 2009; Armstrong and Erskine, 2010). Sweep pattern, pier-walk pattern, snag-line search, and overhead search are all variations of a search with one diver and a tether, which is a line connecting the diver to a person out of the water or to the boat (Becker, 1995; Armstrong and Erskine, 2010). These search methods can be used when searching for large items or small items. Grid pattern searches employ a square grid, usually made out of PVC pipes to search an area for smaller items. Finally, divers can utilize hand-held sonar to assist them in their searches for large or small items. Each of these methods has advantages and disadvantages based on the terrain and the missing target (Armstrong and Erskine, 2010).

A sweep pattern employs a stationary tether, and one diver. The tether can either be a person on shore, or the boat. The diver swims to the end of the tether line and sweeps back and forth. After each pass, the tether shortens the line, and then the diver does another a pass. This results in a wedge-shaped search area, but allows the diver to move closer to the boat with each pass as fatigue increases (Becker, 1995; Armstrong and Erskine, 2010). In a pier-walk pattern, the tether walks with the diver for each pass. As with the sweep pattern, the tether pulls the diver in with each pass, but since the tether is walking with the diver, the search pattern is rectangular, rather than wedge shaped (Becker, 1995; Armstrong and Erskine, 2010). A snag-line search employs the tether line in the search, since the diver attempts to snag the tether line on the missing item. In all of these search methods, a diver is connected to a tether via a line; therefore,

if there are obstacles in the path of the search, the tether line could become entangled in the obstacle, obstructing the search and possibly endangering the diver (Becker, 1995). However, if obstacles are present in the search area, an overhead search can be employed. In overhead searches, the diver searches an area, comes up to avoid obstacles, and then goes back down to search another area. The line goes up to the surface of the water. This prevents the line from snagging on unseen obstacles (Armstrong and Erskine, 2010). Since the tether line allows the diver to communicate with the tether person in case there is an issue underwater, the appropriate search method must be employed to prevent the tether line from inhibiting diver-tether communication. Additionally, the tether line allows the tether to assist the diver back to the boat in case of fatigue or emergency (Armstrong and Erskine, 2010).

For smaller items, a grid search, consisting of a square of PVC pipes, will frequently be utilized to ensure the entire search area is completely covered. The pipes fill with water to keep the grid on the bottom of the search area. The diver then searches the area with their hands and, after searching the entire area, folds the grid over one side and searches the next area (Armstrong and Erskine, 2010). While this method will take much longer than the tether line searches, it allows the diver to thoroughly search an area (Armstrong and Erskine, 2010). This method is especially useful when searching for small items, or when there is little to no visibility.

Regardless of the search pattern selected, the effectiveness of a diver search is influenced by visibility and diver experience. In a controlled research study to evaluate the accuracy and precision of diver estimated abalone counts, diver experience was found to drastically affect the success of the search (Gorfine et al., 1998). More experienced divers were able to search longer and with fewer issues, such as diver equilibrium or line entanglement. Additionally, there was a large degree of variance in the counts between divers for each transect line (Gorfine et al., 1998).

While this research investigated abalone counts, it applies to all diver searches, especially searches involving small targets. Therefore, when searching for small evidence, divers should ensure that transects overlap so that each area is covered by at least two divers, if not more.

While dive teams can be deployed quickly and effectively, there are also disadvantages to utilizing divers for water searches. Diver health is one of the main concerns as a myriad of health issues can be related to diving including, but not limited to nitrogen narcosis, decompression sickness, hypothermia, hyperthermia, or injury. Moreover, divers are more likely to have cognitive, musculoskeletal, and hearing issues than non-divers (Ross et al., 2007; Bowens, 2009). Moreover, inclement weather and strong currents can require additional equipment, such as a tow sled, increase diver fatigue, or even prevent divers from entering the water (Becker, 1995; Labatt, 2008). Contaminated water is another health concern to the diver (Winskog, 2011). When there is a risk of contaminated water, divers should utilize a dry suit and decontamination procedures should be carried out prior to the diver removing the suit (Becker, 1995; Becker, 2006). Additionally, as the study by Gorfine et al. (1998) demonstrates, diver searches lack the accuracy required to search for small objects, and if the divers are inexperienced, the search can be prolonged, requiring additional manpower and increasing diver submerged time.

Cadaver Dogs

Air scent dogs, which include cadaver dogs, were first utilized by the U.S. Navy to detect enemy swimmers. By the mid-1980's, air scent dogs were employed in water searches for missing people (Osterkamp, 2011). Air scent dogs can also pick up the scent of a specific human and trace the person; however, a specific type of air scent dog, cadaver dogs, detect human decomposition. While there is limited published studies on the accuracy of cadaver dogs in

water, their use has been investigated in snow (Komar, 1999). In this study, the success of the search was affected by the familiarity of the dog with the scent and the experience of the dog and handler in the specific environment (Komar, 1999). Similarly, for water searches, cadaver dogs should be familiar with searching in the aquatic environment. However, despite the limited research on the success of cadaver dogs in water searches, case studies have reported that cadaver dogs are a viable option for forensic water searches.

When a cadaver dog is used to search a water environment, the dog, who should be certified or trained for searches on the water, is positioned in the boat, typically in the bow, with its handler. The boat should be as low in the water as possible. The dog searches the air above the water, and signals to the handler if it hits on a scent. At that time, a buoy should be used to mark the location (Rebmann et al., 2000). However, cadaver dogs are limited by a number of variables, such as the presence of remains, presence of scent above ground, air movement between scent and dog, the air temperature, cadaver dog ability, and handler ability (Rebmann et al., 2000). While not specifically stating the effect on water searches, these variables will also influence a cadaver's dog ability to detect submerged remains. Despite these variables, Armstrong and Erskine (Armstrong and Erskine, 2010) report two case reports in which air scent dogs successfully located the missing person. In the first case, the dog first detected the missing child while in a canoe on the water. Then, the dog was able to trace the scent back to the shore, where the child was discovered, alive, in the woods. In the second case, a cadaver dog was employed to search for a submerged body that had been missing for 192 days. The dog alerted on the body and on another spot in the river where human bones were discovered. The pathologist determined that the bones found were not submerged longer than a year. These two

case studies are successful in demonstrating that air scent dogs are an effective tool on water as well as on land.

Metal Detectors

Metal detectors can be utilized to search for objects containing conductive metal or some minerals. Since metal detectors can be operated underwater, they are a viable option for the detection of forensic evidence or even a submerged body if the body has metallic objects associated with it. Metal detectors can even detect objects under the soil and thus be used to detect objects underneath the bottom surface. A study on the detection of lead objects underwater found that the depth of a buried object that a metal detector can discern is proportional to the mass of the object. An object with a mass of 0.4 g can be discerned to a depth of 1.6 cm beneath the soil, and if the object has a mass greater than 3.5 g, then it can be detected up to a depth of 10 cm (Duerr and DeStefano, 1999). Therefore, even if the missing item was buried over time, the metal detector may still be able to discern its location.

Similar to terrestrial searches with a metal detector, the metal detector should be swept over the search area in overlapping passes (Bowens, 2009). If the body of water is deep, a diver may be required to operate the metal detector, and a specialized metal detector that can be completely submerged is required (Connor and Scott, 1998). Additionally, if the metal detector is employed in salt water, the detector must utilize a pulse-induction technology so that the minerals in the salt water do not interfere with the detection of the object (Connor and Scott, 1998). However, underwater metal detectors are most successful when searching for items that are of a reasonable size, such as larger than a coin, and good electrical conductivity (Foster, 1970).

Magnetometers

Magnetometers, like metal detectors, also detect ferrous objects. However, in addition to the hand-held version, magnetometers can be deployed in a towfish, similar to side-scan sonar, or on a floatation device, similar to ground-penetrating radar. The towfish is utilized when the magnetometer is deployed from metal boats to prevent the boat from being detected. However, in order to use the towfish, the water must be deep enough because the towfish must be lowered until it cannot detect the boat. All three deployment types can be utilized to detect differences in magnetic potential (Conlin and Russell, 2006; Parker et al., 2010). Magnetometers have been used by underwater archaeologists to locate shipwrecks, and can be utilized for forensic contexts, such as in the detection of forensic evidence, body disposal containers, or even wreckage material from planes (Jackson, 2002; Conlin and Russell, 2006; Parker et al., 2010). Recently, more sensitive systems can even detect ancient hearths and ceramic assemblages (Bowens, 2009). However, the sensitivity could create additional clutter in areas with urban debris such as ports or other coastal areas. Using multiple magnetometers in a fixed array can decrease the noise created by debris and allow large objects, such as wrecks, to be differentiated from normal debris (Bowens, 2009). Additionally, transect spacing must be considered when using magnetometers; the transects should account for the size of smallest item to be located and allow for overlap of transects (Arnold III, 1996).

Jackson (2002) discusses the use of a magnetometer to locate a murder victim that was dumped in a car in the Missouri River. The magnetometer was selected by NecroSearch because the terrain of the river prevented the use of side-scan sonar, and the percentage of ferrous material in the composition of the car suggested that the magnetometer would easily detect it. The magnetometer was able to locate several anomalies, which were prioritized by the

investigators. The first anomaly located a car, but not the correct one. The second anomaly proved to be the victim's car, with the remains of the victim inside.

A magnetometer was also used to locate the *Belle*, a French ship that sank in 1686 (Arnold III, 1996), and this technology was utilized to locate a T-6 Harvard airplane that crashed into the Mediterranean Sea near Israel (Weiss et al., 2007). The magnetometer identified numerous unassociated objects in this search, including a 5th century Byzantine iron anchor, a thick walled steel tube, and an aircraft flare from the 1960's or 1970's (Weiss et al., 2007).

Ground-Penetrating Radar

Ground-penetrating radar (GPR) is a non-invasive technique that identifies anomalies in the water column or bottom surface. Using electromagnetic waves, GPR detects contrasting material by reflecting or refracting off of the material, and this reflection is captured by the antenna. With GPR, targets appear as a hyperbola and the true morphology of the shape cannot be discerned (Dupras et al., 2011). Anomalies identified must be further investigated by divers. Ground-penetrating radar can detect anomalies in the water column, as well as the bottom surface of a body of water or even ice. This technology is often used for sedimentation studies, civil engineering, and hydrological studies (Parker et al., 2010). However, it can also be applied to archaeological and forensic archaeological contexts in water environments (Ruffell, 2006; Parker et al., 2010; Dupras et al., 2011). Since the radar frequencies can penetrate the subsurface, it can also be used as a sub-bottom profiler to detect anomalies below the subsurface. However, variables such as the depth of the water and the composition of the subsurface can affect the depth of penetration (Beres Jr and Haeni, 1991). Additionally, the frequency of the antenna will affect the depth of penetration. Higher frequencies will provide higher resolution, which is the ability to distinguish between two distinct objects (Johnson and Helferty, 1990), but

poorer penetration. The higher resolution may pick up more clutter in the area, which will make anomalies difficult to discern. Conversely, lower frequencies will have lower resolution, but penetrate deeper (Beres Jr and Haeni, 1991).

Ground-penetrating radar is a useful technique for searching large areas rapidly and non-invasively. This tool can also penetrate vegetation that can prevent the use of other techniques such as divers or side-scan sonar (Parker et al., 2010). Ground-penetrating radar will identify anomalies that can be further investigated by divers. However, it cannot be used in saline environment due to increased conductivity of the salt (Parker et al., 2010). Moreover, using GPR over water can have additional challenges. For example, GPR is also affected by metal, and therefore, it cannot be used in a metal boat. Instead, it should be employed in a non-metallic craft, or it can be suspended by cable over the water. Also, waves or uneven surfaces can cause false anomalies. Suspending the antenna on a cable over water or waterproofing the antenna and submerging it in the body of water can minimize the disturbances of turbulent water (Parker et al., 2010).

Conducting a search with GPR requires running transects over the body of water. To do this, a global positioning system (GPS) unit can be used in conjunction with the GPR to ensure that the transects overlap and the entire search area is covered. When GPR is conducted in conjunction with GPS, the position and path of the boat can be monitored by the driver of the boat. The driver can then guide the boat across the search area and ensure the entire search area is covered (Bowens, 2009).

Ground-penetrating radar has been successfully employed to locate a sunken jet ski (Ruffell, 2006). The jet-ski was involved in a boating accident in shallow lake in Northern Ireland. The lake shore consisted of sand and pebbles, but progressed to silt and mud

approximately 5 m from shore. Diver searches proved unsuccessful because the divers would stir up the silt from the lake bed, hampering visibility. Instead, GPR was employed, and antennae with 50 MHz, 100 MHz, 200 MHz, and 400 MHz frequencies were utilized and compared. In this case, the 200 MHz antenna proved to be the most effective antenna. The reflection profile from the 200 MHz demonstrated a clearly discernible hyperbola above the lake bottom. This proved to be the hull of the jet-ski (Ruffell, 2006).

Side-Scan Sonar

Side-scan sonar is another geophysical technique that forensic archaeologists and law enforcement agencies have been utilizing with increasing frequency. The effectiveness of the technique and its advantages over diver searches has made side-scan sonar the preferred choice for water searches when it is available (Teather, 1994). Quinn et al. (2002) found that a geophysical survey, such as one with side-scan sonar, provides a quick and effective survey method, although it is dependent on the experience of the operator, the navigation by the driver, and the quality of the image. Side-scan sonar has been utilized in a number of high-profile cases, and is frequently employed to search for bodies in water environments (Garrett, 2006; Atherton, 2011). Sonar searches are conducted in a similar manner to searches with GPR; hence, side-scan sonar allows a larger area to be searched and decreases the time required to search the area. Like GPR, when features are identified by side-scan sonar, they should be further investigated by divers. However, unlike GPR, side-scan sonar images provide photograph-like images (Dupras et al., 2011).

There are two types of side-scan sonar in current use. One type, the handheld sonar unit, can be wielded by divers to assist them in the search (Armstrong and Erskine, 2010). The diver holds the sonar unit as they swim over a site, and an audio unit processes the returns from the

sonar and sends it to the diver's earphone. The tone will change based on the diver's distance to the target. The diver should hold the sonar as close to the bottom as possible so that the returns are more effective. Another type of sonar is deployed from a boat. A towfish is towed from a boat. A cable runs from the towfish to a monitor on the boat (Figure 1) where an operator interprets the returns (Singh et al., 2000).

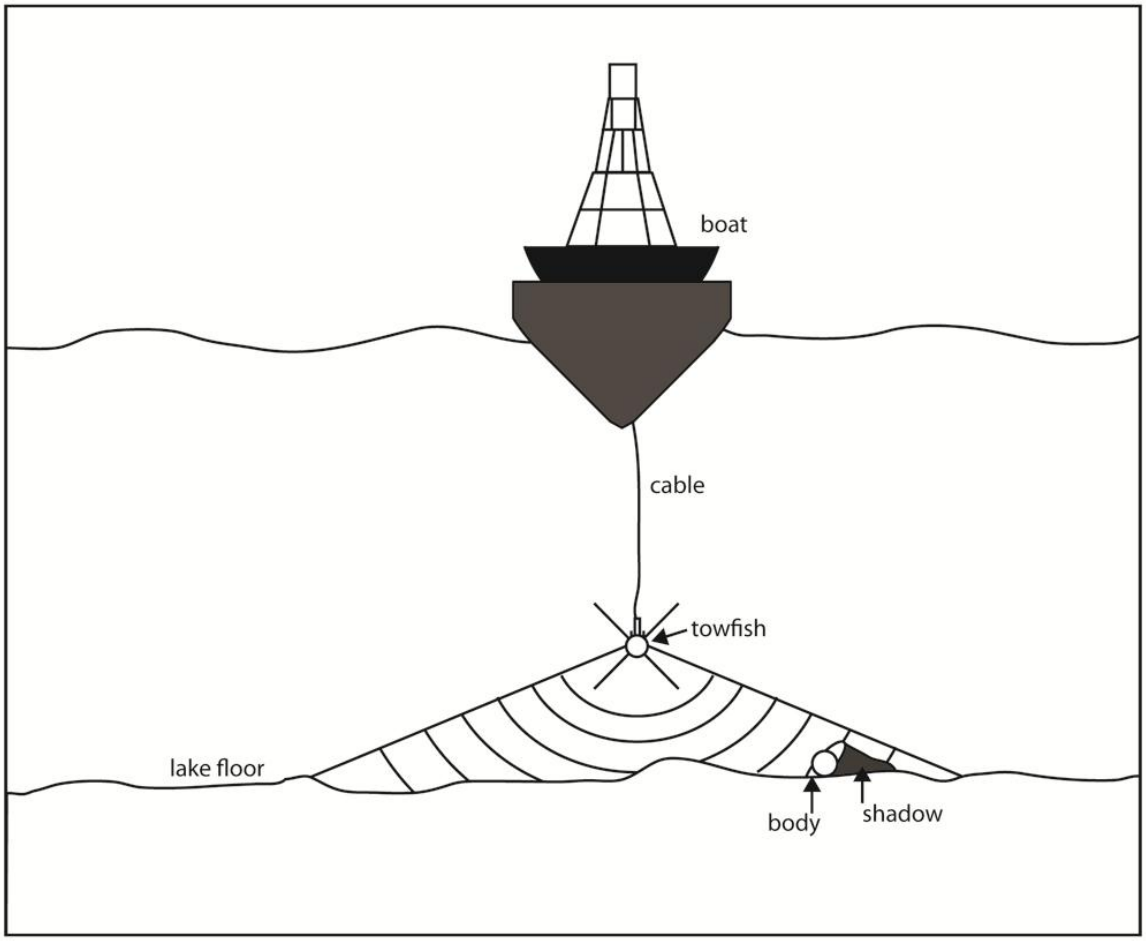

Figure 1: Diagram of how sonar detects features; the body blocks the acoustic signals, creating a "shadow" behind the feature.

Side-scan sonar has been applied to numerous hydrological applications. It was developed to survey and map the seafloor, although its current applications have expanded beyond this limited purpose. Since its development in the 1960's, side-scan sonar has been employed to investigate a bridge that collapsed in 1879 (Duck and Dow, 1994) and to located

subaqueous features (McManus and Duck, 1983). Additionally, this technology has been utilized to record changes in subaqueous features in the Mississippi River delta (Coleman, 1988), and to monitor dredge tracks and explore terraces formed by the roots of dead plants (Newton and Stefanon, 1975).

Soon after the development of side-scan sonar, the technology was employed in archaeological contexts. Literature discussing guidelines for the application of this technology to archaeological surveys can be found as early as the 1960's (Hall, 1966). Since then, this technology has assisted number of archaeological projects, including locating shipwrecks, airplanes, and submerged prehistoric sites (Andrews and Corletta, 1995; Quinn et al., 2002; Faught, 2004; Marks, 2006; Dumser and Türkay, 2008; Sear et al., 2011). Additionally, more recently, side-scan sonar has been replacing divers in forensic water searches. Some high profile cases, such as the search for Natalee Holloway incorporated this technology to assist in the search (Garrett, 2006). Ralston and Pinksen (2010) and Atherton (Atherton, 2011) discuss several case studies in which side-scan sonar was employed to locate submerged bodies. However, as the incorporation of side-scan sonar is a recent phenomenon, there is a lack of literature on the advantages of employing side-scan sonar as well as the limitations of this technology.

Table 1: Advantages and Disadvantages of Water Search Techniques.

Search Technique	Advantages	Disadvantages
Diver teams	• Relatively inexpensive • Easy to deploy • Effective • Find and recover	• Health risks • Success affected by diver experience • Requires significant manpower • Can be invasive
Cadaver dogs	• Requires less manpower • Easy to deploy • Does not require diver to operate	• Questionable success • Requires some level of decomposition
Metal Detectors	• Can be utilized by divers • Detects objects underneath the bottom surface • Relatively inexpensive	• Detects only conductive metal and some minerals • Covers small area
Magnetometers	• Covers large areas • Detects objects underneath the bottom surface • Detection increased to even small amounts of ferrous material, such as an ancient hearth. • Does not require diver to operate, can be hand-held	• Expensive • Cannot be employed in urban water environment (i.e. pier area or shipping lanes) due to excessive noise. • Only detects ferrous material
Ground-Penetrating Radar	• Covers large areas • Detects objects underneath the bottom surface • Does not require diver to operate, but can be hand-held • Requires less manpower • Can be deployed in inclement weather	• Difficult to deploy • Expensive • Requires experienced operator
Side-Scan Sonar	• Covers large areas • Does not require diver to operate • Requires less manpower • Provides photo-like images of bottom • Can be employed in inclement weather • Can be utilized after dark • Can be utilized in freshwater, brackish water, and saltwater	• Expensive • Cannot be used in areas with vegetation • Requires experienced operator

Sonar Use and Operation

Sonar, an acronym that stands for sound navigation and ranging (Lurton, 2002), is a way to measure sound in relation to time (Atherton, 2011). A side-scan sonar system typically consists of a projector and a hydrophone in a towfish (Figure 2), which is connected to a boat via a cable (Figure 1). The projector and hydrophone, collectively called transducers, emit acoustic pulses and receive the pulses, respectively (Flemming, 1976; Fish and Carr, 1990; Atherton, 2011). In monostatic systems the transducer sends and receives the acoustic pulses, but in bistatic systems, the projector and hydrophone are separated (Atherton, 2011). For side-scan sonar systems, multiple monostatic transducers are employed, interconnected in a linear array (Johnson and Helferty, 1990). The acoustic signals of these transducers are focused in a downward and lateral angle by inserting the elements into holders that prevent the signal from projecting in other directions (Johnson and Helferty, 1990; Atherton, 2011).

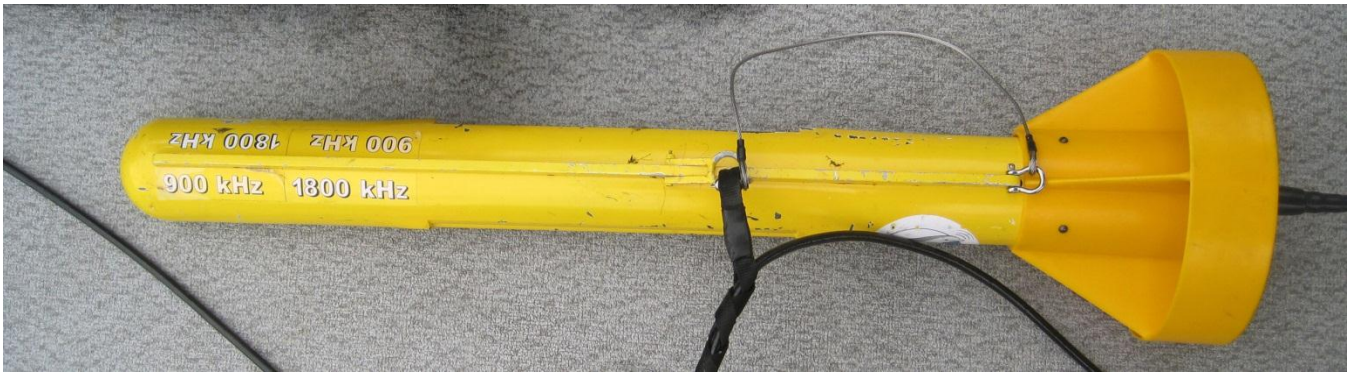

Figure 2: Centurion Sea Scan dual frequency side-scan sonar towfish

As a monostatic sonar system, side-scan sonar is able to send and receive acoustic signals by cycling the transducers between operating as a projector and as a hydrophone. After the transducers emit acoustic signals for 5 to 1000 microseconds, the voltage stops, and the transducers receives the return echoes. Once the transducers are reset, they transmit sound again, and the cycle continues (Atherton, 2011). The projector converts electrical signals into pressure

waves, which propagate through the water and reflect off of objects back to the hydrophone receiver (Fish and Carr, 1990; Lurton, 2002). The strength of the frequency returning to the hydrophone is interpreted and translated into electrical signals, which return to the monitor on the boat via a cable. This system allows for real-time analysis of the bottom substrate. Additionally, a global positioning systems (GPS) receiver is attached to the sonar unit or the boat and monitors the path of the sonar to ensure the entire search area is covered (Figure 3).

Figure 3: Pontoon boat that OCSO uses to deploy side-scan sonar with equipment labeled

The towfish is towed by a cable from the boat, and therefore, the speed of the boat must account for the towfish so that the towfish is level during the sonar process. Sonar should not be operated during a turn, because the sonar would be distorted (Flemming, 1976). Searches with side-scan sonar typically follow parallel transects in which each transect overlaps 50% of the previous transect. The spacing of the transects are determined by the swath width of the sonar

(Bowens, 2009). Additionally, the operator also controls the depth of the towfish, since the towfish is most effective when it is as close to the bottom as possible.

Many side-scan sonar systems now provide the option to choose between two frequencies. The frequency affects the distance the acoustic signals can travel as well as the resolution of the images. Lower frequencies can travel farther distances, but higher frequencies have better resolution (Singh et al., 2000). Therefore, higher frequencies are more likely to discern between two closely spaced objects, but these frequencies will also provide additional clutter due to increased sensitivity.

Sonar Imagery

Side-scan sonar produces images akin to an aerial image of the bottom surface, which has increased the use of this technology as a remote sensing technique in water environments (Ravichandran, 2005; Dupras et al., 2011). The images produced provide the best resolution of all geophysical technologies for submerged body and evidence searches (Dupras et al., 2011). The image resulting from a side-scan sonar survey has several distinct features (Figure 4). Recognizing these features allows the sonar operator to better interpret the record.

Fish and Carr (1990) discuss the various aspects of the sonar image. The trigger pulse is the first return echo, although it is often synonymous with the path of the towfish. The surface of the water may be present on the record if the towfish is towed close to the surface. When this happens, a line will be present in between the trigger pulse and the first bottom return. When the first surface return is present, it can be used to determine the depth of the towfish. The first bottom return is the first return echo received off of the bottom surface. The closer the towfish is to the bottom, the closer this will be to the trigger pulse. In between the first bottom return and the trigger pulse is an area known as the water column. If there are any features in the water

column, it may be clutter or noise caused by the water surface reflecting pieces of the acoustic signal. Features on the bottom surface in between the trigger pulse and the first bottom return will not be visible.

In addition, features within the sonar image will contrast with the bottom surface based on their reflectivity. Metal and rock are good reflectors due to their rough appearance and will contrast more than objects with a lower reflectivity coefficient (Fish and Carr, 1990; Ravichandran, 2005). Additionally, a greater contrast between the bottom surface and the feature will create more visibility for that feature. For example, a feature that has more height will be more visible, and a flat bottom surface will allow features to be more discernible. Behind the feature will be a shadow cast by the feature blocking the acoustic signals. Often the shadow will provide more information on the morphological characteristics of the object than the image of the feature itself (Figure 5) (Atherton, 2011). For example, a bicycle may appear as a long thin feature, but the shadow will present as a bicycle, as the acoustic signals go through the spaces between the frame and the spokes (Atherton, 2011). Depressions appear similar to the shadow of a feature, but they will not have the same contrasting object in front of it. The shadow also differentiates features from noise or feedback. Often noise or feedback can resemble a feature, but only a feature will have a shadow, which indicates the vertical aspect of the object (Figure 5) (Singh et al., 2000).

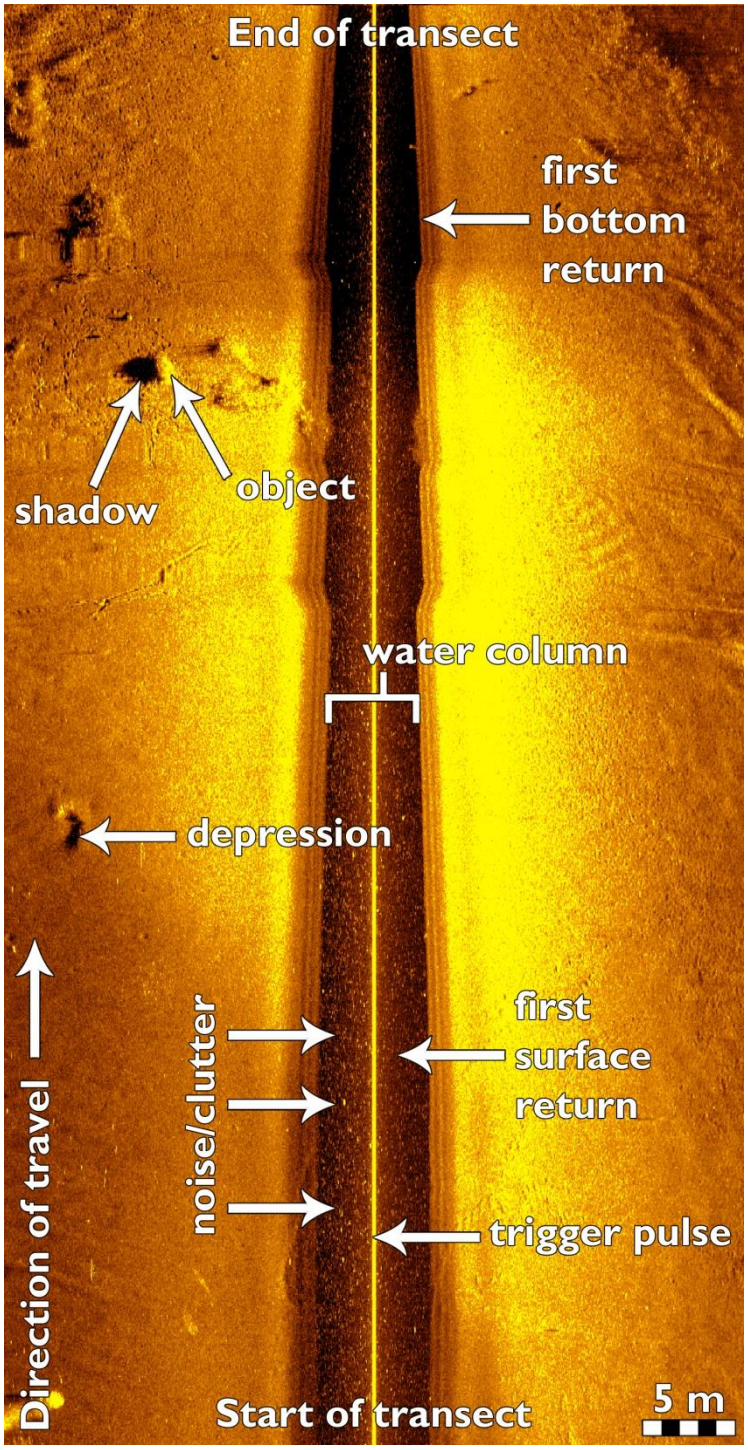

Figure 4: Sonar image with features labeled; acoustic signals transmitted out of both sides of the towfish

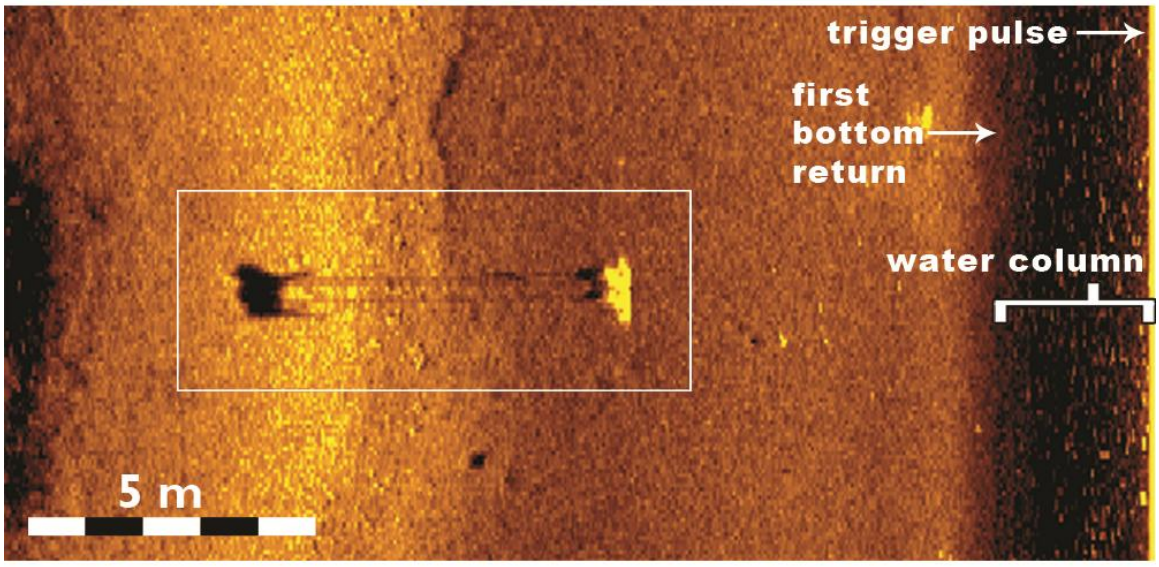

Figure 5: Sonar image demonstrating the morphology of the shadow of a sonar feature. The feature (pig carcass) is on the right inside the white box, while the shadow, on the left, indicates the shape of the pig carcass. Acoustic signals transmitted out of the left side of the towfish.

Additionally, the acoustic signals can be emitted out of the towfish on the left side, the right side, or both sides. Figure 4 illustrates an image in which the acoustic signals are propagated out of both sides of the towfish, while in Figure 5 the acoustic signals are only transmitted out of the left side of the towfish. If the signals are sent out of only the left side, the trigger pulse would appear along the right margin, while if signals are sent out of only the right side, the trigger pulse would appear along the left margin.

Advantages and disadvantages of sonar

Side-scan sonar can be employed when the risks are too great to utilize divers. For example, inclement weather, nighttime or contaminated water does not impact its effectiveness, even though divers cannot be deployed in the same conditions. However, a number of variables can influence the success of a search with side-scan sonar. Different materials will have different reflective properties (Fish and Carr, 1990; Arnold III, 1996; Ravichandran, 2005). For example, rock and gravel will reflect acoustic signals better than sand, which will reflect signals

better than mud, while vegetation and rapid changes in depth can camouflage anomalies. Therefore, materials will appear differently on the sonar images based on their reflective properties. Since rock and gravel will demonstrate greater contrast than sand or mud, a target accompanied by these materials will increase the visibility of the target. However, vegetation may obscure targets, preventing their detection. Other variables that can interfere with a side-scan sonar search are seismic instruments, dense particle suspension in the water column, and ultrasonic waves created by passing ships (Flemming, 1976). Therefore, side-scan sonar should be conducted prior to any other surveys to prevent interference from the other surveys.

Research Objectives

The primary objective of this research is to establish a set of best practices for the use of sonar in forensic contexts. The research design will involve establishing a controlled area in which sonar can be employed to detect pig carcasses, which will be utilized as proxy cadavers. This research will (1) document the ability of side-scan sonar to detect submerged firearms, (2) incorporate real-life scenarios for submerged bodies, (3) document the ability of side-scan sonar to detect submerged remains over time, and (4) evaluate the variables that affect the success of a forensic water search.

Thesis Outline

This thesis will be separated into four chapters: Chapter 1 will provide an introduction to this research; Chapter 2 will discuss the use of side-scan sonar for submerged forensic evidence, focusing on street-level firearms; Chapter 3 will present the results of the controlled research on detecting submerged remains using proxy cadavers including the effects of terrain, decomposition, frequency, and range on the discernibility of submerged remains; and Chapter 4 will discuss the best practices for applying side-scan sonar in forensic contexts.

CHAPTER TWO: THE USE OF SIDE-SCAN SONAR TO LOCATE SUBMERGED FIREARMS

Introduction

Bodies of water are often used as a dump site to obscure evidence of a crime. However, law enforcement agencies have a number of resources they can employ to recover forensic evidence. Dive team searches, metal detectors, magnetometers, ground-penetrating radar, and side-scan sonar are all geophysical tools that can be employed in the search for forensic evidence. Each method has advantages and disadvantages for its use in a search based on the materials associated with the forensic evidence, the terrain of the body of water, and the manpower available (Table 1). A thorough understanding of the advantages and disadvantages of each tool, the composition of the target, and the size of the search area can assist agencies in selecting the appropriate search technique.

One of the first considerations when selecting the appropriate geophysical method to employ for a forensic evidence water search is the composition of the evidence. Geophysical tools will detect a variety of materials with varying success rates. Therefore, the geophysical tool that best detects the suspected material should be employed. Additionally, geophysical tools have advantages and caveats for searches. For example, GPR, metal detectors, and magnetometers can detect items below the surface, but side-scan sonar cannot (Dupras et al., 2011). Table 1 lists the advantages and disadvantages of water search techniques and this list should be referenced when evaluating the appropriate search tool for forensic evidence water

searches. This aspect of the research will focus on the applicability of side-scan sonar to the search for firearms.

Purpose

The research presented will provide a foundation for understanding the application of side-scan sonar to forensic purposes. This aspect of the research will (1) determine the ability of side-scan sonar to detect submerged firearms in freshwater ponds and lakes and (2) determine the best collection parameters for searching for submerged firearms in freshwater ponds and lakes.

In order to complete this aspect of the research, the assistance of the Orange County Sheriff's Office (OCSO) Marine Unit, Dive Team, and Forensic Unit were enlisted. Marine divers were employed to place the firearms that the Forensic Unit provided on the lake bottom. They also collected the firearms immediately following data collection, and therefore, a shallow area was chosen to minimize the submerged time of the divers. The slope of the lake in this area was approximately 3^{o}. One limitation of the data collected was due to equipment malfunction. The transducers were only able to send acoustic signals out of one side of the towfish, and as such, transects could only be conducted in a north to south direction.

Materials and Methods

Evidence and Research Site

Orange County Sheriff's Office Marine Unit is often called to recover forensic evidence from waterways. While the majority of the evidence is large, such as stolen cars, OCSO Marine Unit has been requested to locate smaller items, such as long guns and hand guns. This research is investigating the application of side-scan sonar to search for small to medium sized firearms in order to determine whether law enforcement agencies should employ sonar in addition to divers when this type of evidence must be recovered. Five firearms were tested: three long guns and

two hand guns. These items were chosen as a representative sample of the street-level firearms OCSO is frequently asked to recover. Table 2 lists the model, dimensions, and composition of each firearm, and Figure 5 provides images of the items.

Table 2: List of commonly found forensic evidence utilized in this project

Make	Type	Metal Composition	Length (cm)	Width (cm)
Winchester 74	.22 rifle	Steel	106	13
Remington 870	Shotgun/12 Gauge	Steel	122	13.5
Marlin 1895SS	45/70 rifle	Steel	102	12
Lorcin L25	.25 Semiauto pistol	Aluminum frame, magazine, steel slide	12.2	9
Hipoint JCP	.40 Semiauto pistol	Steel/Polymer	25.4	15.6

Figure 6: Firearms utilized in the side-scan sonar search: a) Winchester 74, b) Remington 870, c) Marlin 1895SS, d) Locin L25, e) Hipoint JCP

The research site is a borrow pond located within the Hal Scot Regional Preserve (Figure 7) in Wedgefield, Florida. St. John's River Water Management District granted special use authorization for the site for this research (APPENDIX A: SPECIAL USE AUTHORIZATION).

A clear shallow area was utilized to aid the divers in placement and recovery of the forensic evidence (Figure 8).

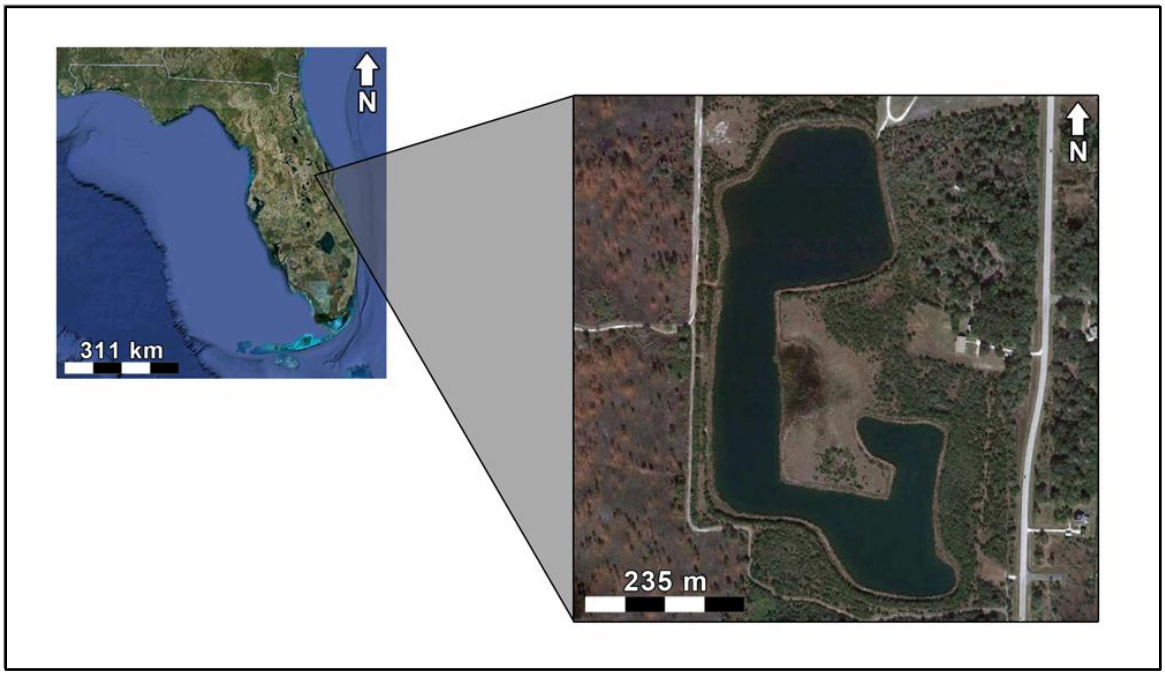

Figure 7: Location of research site in Wedgefield, Florida and close-up of research site

Figure 8: Approximate location of each firearm within research site

Data Collection

A Centurion Sea Scan dual frequency side-scan sonar towfish was employed for this study (Figure 2). This sonar system received the second highest overall score from U.S. Department of Homeland Security's System Assessment and Validation for Emergency Responders (System Assessment and Validation for Emergency Responders, 2009) based on its affordability, ease of use, portability, easy system setup, resilient equipment, and readable screen. The towfish could operate at either 900 kHz or 1800 kHz and a swath width of 10 m, 20 m, or 30 m. A pontoon boat was utilized to tow the side-scan sonar (Figure 3). The towfish was connected to the control unit via a cable, and the towfish was towed from the front of the boat (Figure 1). Additionally, a GPS was connected to the sonar control unit to establish the GPS coordinates of the towfish.

Divers placed the evidence approximately 1 m apart in a north-south direction approximately 3 m from shore (Figure 8). Four surveys were conducted for four different combinations of frequency and swath width: 900 kHz, 10 m; 900 kHz, 20 m; 1800 kHz, 10 m; and 1800 kHz, 20 m.

Each firearm was scored for each transect. The firearm received a score of "excellent" if the firearm was easily discernible or if the shadow of the firearm could be discernible as a firearm. A score of "good" was given to images in which the features were not easily identified as a firearm, but were distinct from the surroundings enough to be determined as a feature. Easily discernible was defined as either a distinct feature or a distinct shadow. A score of "possible" was given to the image if it there was a possible, but indistinct shadow or if the feature could not be definitively identified as the firearm, and "none" if it was not visible.

Results

As Table 3 illustrates, side-scan sonar was unable to definitively discern firearms in this study. Even though four different swath width and frequency combinations were employed, none of the targets could be easily discerned from the surrounding area (Figure 9). However, there are shadows that could be interpreted as the targets, but they are not distinct enough to be discerned from the surrounding areas as a target. Instead of appearing as contrasting features, they appear as depressions. The long guns, ranging between 102 cm and 122 cm in length, were possibly visible, but the hand guns, ranging between 12.2 and 25.4 cm in length were not visible. Therefore, as the size of the object increases, the likelihood of detection also increases. Additionally, the 20 m swath width shows more possible features than the 10 m swath width, although the possible features that appear for the 10 m swath width are larger and more visible than the 20 m swath width. Finally, more shadows were identified with the 900 kHz frequency, but the shadows on the transects taken with the 1800 kHz frequency were more distinctive.

Table 3: Scoring table for firearms search

	Evidence	Frequency	Swath width	Visibility
Long guns	Winchester 74	900	10	None
	Winchester 74	900	20	Possible
	Winchester 74	1800	10	None
	Winchester 74	1800	20	Possible
	Remington 870	900	10	Possible
	Remington 870	900	20	Possible
	Remington 870	1800	10	None
	Remington 870	1800	20	Possible
	Marlin 1895SS	900	10	Possible
	Marlin 1895SS	900	20	Possible
	Marlin 1895SS	1800	10	Possible
	Marlin 1895SS	1800	20	Possible
Hand guns	Lorcin L25	900	10	None
	Lorcin L25	900	20	None
	Lorcin L25	1800	10	None
	Lorcin L25	1800	20	None
	Hipoint JCP	900	10	None
	Hipoint JCP	900	20	None
	Hipoint JCP	1800	10	None
	Hipoint JCP	1800	20	None

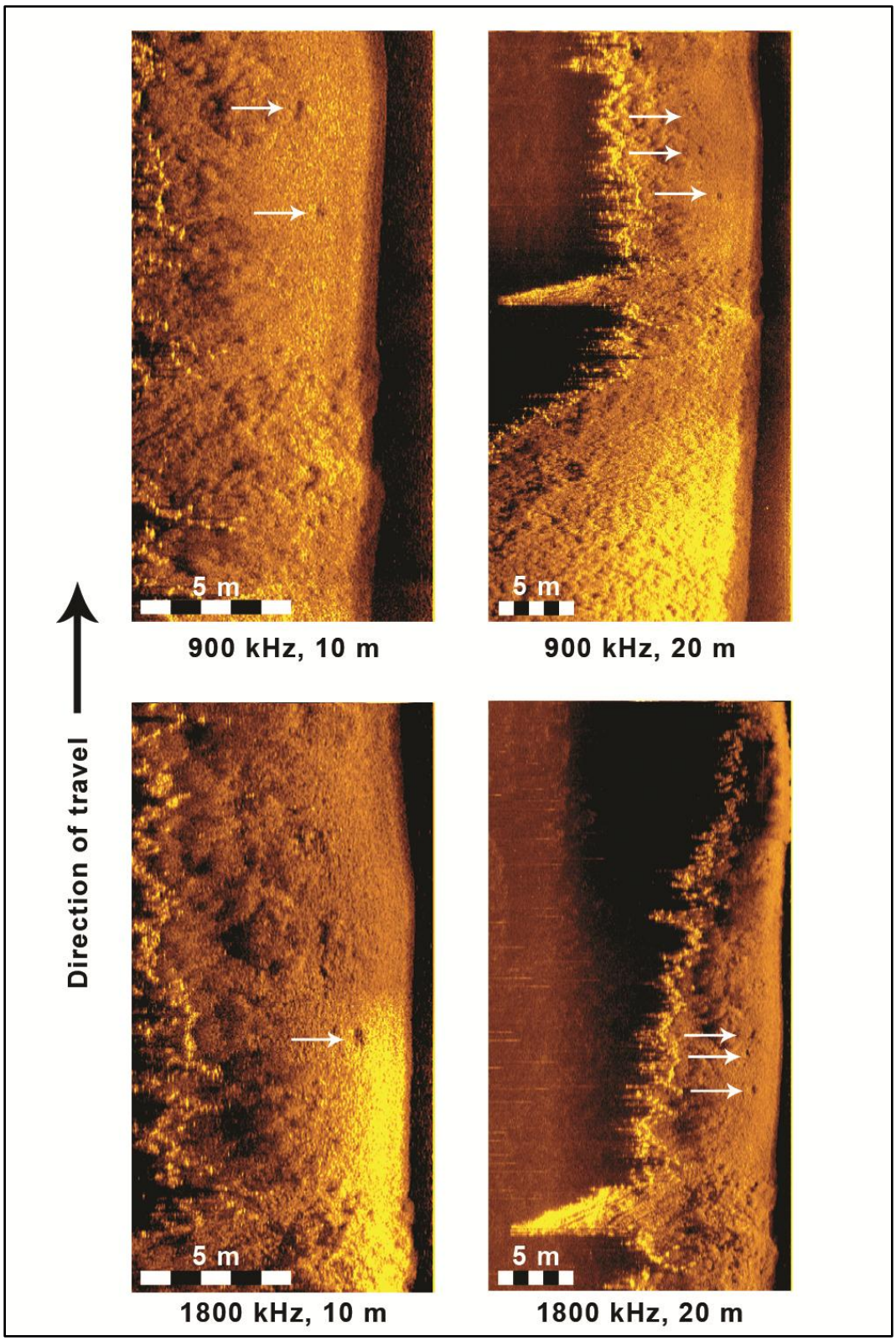

Figure 9: Sonar images of firearms from each transect; each transect contained all five tested firearms; arrows indicate the shadows of possible firearms.

Conversely, side-scan sonar can easily discern larger items of forensic evidence. Boats, automobiles, and even helicopters are readily identifiable (Figure 10). While large debris may obscure the larger items as well, terrain is less likely to affect the detection of larger items of evidence since the size of the object contrasts with the surrounding environment. With larger evidence, side-scan sonar provides detailed information about the target. For example, with the automobile, the windshield is discernible, and with the boat, the outline of the hull is visible.

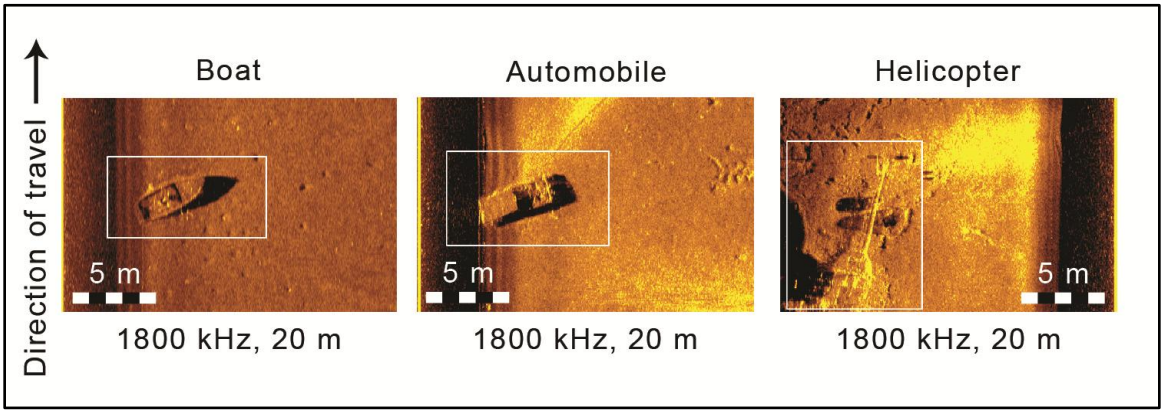

Figure 10: Sonar images of boat, automobile, and helicopter detected by OCSO Marine Unit (Images courtesy of OCSO Marine Unit)

Discussion

Several variables likely prevented the detection of the firearms in this aspect of the research. First, although the area was devoid of vegetation, there was a small amount of silt present. The silt could have obscured the acoustic signals from detecting the firearms, as they were not projecting above the level of silt. Second, the morphology of the object, combined with the silt prevented the presentation of the diagnostic feature with a shadow for each target. Smaller objects are less visible, but objects with more height are more visible. Third, the slope of the bottom likely prevented the shadow that is characteristic of features. Since the acoustic signals were able to penetrate the area behind the target due to the slope, the shadow was not

present and the feature could not be discerned. Even one of these variables could obscure the target, yet the presence of all three prevented the detection of the firearms.

While this research was unable to extract quality images of the firearms employed, that does not exclude the use of side-scan sonar for submerged firearm searches. However, caution must be exercised when employing this technology. If the conditions are ideal, side-scan sonar could recognize submerged evidence, but if there are any circumstances that would obscure the imagery, such as silt, vegetation, or even a sloping terrain, the evidence would not be discernible. When searching for firearms, a 20 m swath width is more likely to discern possible features, and the 1800 kHz frequency will provide more definitive shadows than the 900 kHz frequency.

Therefore, prior to employing side-scan sonar, a test survey of the lake should be conducted to determine the applicability of this technology for the search. If the test concludes that side-scan sonar can be employed, transects should be conducted so that the range of each pass significantly overlaps the range of the previous path. Additionally, any necessary turns should be executed outside the search area. When targets are located on the sonar monitor, the location should be marked with a buoy to allow divers to return to the location and ground-truth it.

Although the firearms could not be definitively detected in this research, the negative results provide valuable information about side-scan sonar. First, caution should be exercised when employing this technology when searching for submerged firearms as the firearms may not be discernible if the conditions are not favorable. Second, additional controlled research must be performed to determine if there are conditions favorable for the detection of submerged firearms, including using additional types of weapons.

Conclusion

Side-scan sonar is a valuable technology for water searches, but caution should be exercised when utilizing sonar to find evidentiary targets. The size of the target, along with the terrain of the bottom surface must be considerations before side-scan sonar is employed. Larger items, such as boats, helicopters, and automobiles are easily discerned despite the terrain, but smaller items, such as long guns and hand guns, will not be visible unless the terrain is ideal. Ideal terrain consists of a flat, sandy lake bottom with no vegetation.

Although this research was unable to discern the firearms utilized, further research is necessary to determine if conditions and parameters exist that would allow the technology to discern firearms. Additional research in areas with ideal terrain, as well as employing a variety of frequencies and ranges to determine the best parameters for discerning firearms should be investigated. Since other sonar systems use frequencies other than the 900 kHz and 1800 kHz frequencies employed in this study, other sonar systems should be employed. Further research will identify not only other variables that prevent the identification of targets, but also variables that allow targets to be discerned from the imagery.

CHAPTER THREE: DETECTING SUBMERGED REMAINS IN A CONTROLLED SETTING USING SIDE-SCAN SONAR

Introduction

When a body search and recovery operation occurs in an aquatic environment, it requires a new set of challenges as opposed to a terrestrial environment. A number of search techniques are available; however, each has its own advantages and limitations. The search technique most applicable to the recovery will depend on a number of variables including the conditions of the water environment, such as terrain and vegetation and the conditions at the time of the search, such as day or night. Therefore, a thorough knowledge of the search tools available will allow investigators to select the most appropriate method. Table 1 discusses the advantages and disadvantages of each search technique.

Side-scan sonar has gaining popularity over other aquatic search methods in forensic contexts since it provides photograph-like images of the bottom surface, which requires less interpretation than other geophysical search methods. This technology can also search larger areas with less manpower than dive team searches. While side-scan sonar have been employed for a variety of uses including marine geology, marine biology, and underwater archaeology (Newton and Stefanon, 1975; Duck and Dow, 1994; Quinn et al., 2002; Faught, 2004; Marks, 2006), the use of this technology in forensic contexts has only recently been explored (Garrett, 2006; Dumser and Türkay, 2008; Ralston and Pinksen, 2010; Atherton, 2011). Throughout the country, and especially in Central Florida, law enforcement agencies have been purchasing side-scan sonar to assist their Marine Units with search and recovery operations on water. Forensic

cases have not only located submerged bodies, but also cleared suspected areas, which allows resources to be focused elsewhere. Table 4 lists the advantages and disadvantages of this technique.

Table 4: The advantages and disadvantages of side-scan sonar in forensic water searches

Advantages	**Disadvantages**
• Non-invasive • Requires less manpower • Search large areas in less time • Can be used in inclement weather • Can be used in darkness and low visibility • Results displayed in real time in the field • Depth and dimension of anomalies can be calculated if the depth of the towfish is known. • Data can be saved on hard drive for computer processing	• Equipment is expensive • Operator must have specialized training • Vegetation can obscure targets • Fluctuations in terrain can obscure targets • Deep silt or mud can prevent target detection • Cannot detect below the bottom surface • Operator and driver need experience for successful searches

Therefore, employing side-scan sonar allows law enforcement agencies to minimize the manpower and time required to search an area, as well as minimize the risks to divers. In other words, this technology allows law enforcement investigators to search larger areas in less time, and with less personnel. By integrating a side-scan sonar search with divers, a body can be found and recovered in significantly less time than typical diver searches. Additionally, searches with this technology will not disturb the context of the scene or any associated evidence. In fact, the sonar images of the area are recorded and saved, allowing for an accurate rendition of the discernible features of the scene even after the scene is disturbed.

Despite the increasing use of side-scan sonar by law enforcement agencies, controlled use of this technology in a forensic context has yet to be conducted. This research seeks to alleviate the lack of literature in the area and provide a set of best practices for the use of the technology. Moreover, the research will identify the benefits and limitations of side-scan sonar when

employed to detect submerged bodies. Finally, controlled research, which provides a structured environment to investigate variables that affect this technology, is an invaluable method to not only understand how specific environmental variables will influence a sonar search, but also allow search and recovery teams to gain valuable experience using the equipment in a controlled setting. The nature of a controlled study provides knowledge and experience to the search and recovery teams that they can apply in forensic searches. Additionally, controlled research bestows the search and recovery teams with an understanding of the local variables that will inhibit or facilitate forensic water searches (Schultz et al., 2006; Schultz, 2007; Schultz, 2008).

Entomological research has identified pig carcasses (*Sus scrofa*) as an appropriate proxy for human cadavers due to the similarity between human and pig decomposition patterns and the ease of which a pig carcass can be obtained (Catts EP, 1992; Goff, 1993). Proxy cadavers are often utilized in place of human cadavers for controlled research with geophysical methods (France et al., 1992; France et al., 1997; Schultz et al., 2006; Schultz, 2007; Schultz and Dupras, 2008; Schultz, 2008; Dupras et al., 2011); therefore, this research will utilize pig carcasses as a proxy to human cadavers

Purpose

The research presented will address the applicability of side-scan sonar to detecting submerged bodies using pig carcasses as proxy cadavers. This aspect of the research will (1) investigate the applicability of side-scan sonar to detecting submerged bodies in freshwater ponds and lakes in a humid, subtropical environment in Central Florida, (2) determine the best collection parameters to employ when searching for submerged bodies in freshwater ponds and lakes in a humid, subtropical environment, (3) determine how the state of decomposition affects

the visibility of the remains on side-scan sonar imagery, and (4) investigate the time interval in which the side-scan sonar can detect submerged remains.

To complete this aspect of the research, the assistance of both the OCSO Marine Unit and the OCSO Dive Team were enlisted, and therefore, data collection was scheduled around each unit's other responsibilities. This limited the days available for data collection as well as the time commitment to collect data. Therefore, when investigating the best collection parameters in Phase 1, at least two of the possible four different sets of parameters were utilized, and if time permitted, three of the four parameters sets were employed. Additionally, Phase 1 was suspended from November 18, 2011 until January 27, 2012 due to previously scheduled responsibilities of OCSO Marine Unit.

Equipment malfunction proved to be another limitation. On the first day of Phase 2, the equipment malfunctioned, and therefore, the high frequency transects could not be collected. However, Brevard County Sheriff's Office loaned OCSO Marine Unit a sonar unit to continue research. The OCSO sonar unit malfunctioned again at the end of this phase, causing all transects to be collected with acoustic signals only sent out of the left side of the towfish.

Additionally, the hurricane ground stakes were unable to secure the pig carcasses to the bottom surface once the pig carcass was bloated. Hence, in Phase 1, Pig 1C had to be relocated, and in Phase 2, all three pig carcasses had to be re-submerged. For Phase 2, each pig carcass was secured with three half cinder blocks and returned as close as possible to their original location. While this affected the decomposition process, since the pig carcasses were floating on the surface of the lake for 1-5 days, this provided valuable information on how to attach objects to the bottom surface for further research studies.

Finally, the location of the project was limited by the terms and conditions provided by the special use authorization given by St. John's River Water Management District necessary to conduct the research. A lake was difficult to locate, and limited the options for possible scenarios. Special use authorization was given by the St. John's River Water Management District for use of the borrow pond in the Hal Scott Regional Preserve, but the terms and conditions had additional limitations on the locations in the lake in which the pig carcasses could be staked and the time interval in which the research could be conducted.

Materials and Methods

Research site

The research site is located on a borrow pond within the Hal Scot Regional Preserve in Wedgefield, Florida (Figure 7). St. John's River Water Management District authorized use of this site for the research project (APPENDIX A: SPECIAL USE AUTHORIZATION). However, the terms and conditions of the permit limited the area in which the pig carcasses could be located to the south two-thirds of the pond and limited the time interval in which the research could be conducted from August 17, 2011 to May 31, 2012. The research consisted of two phases, each utilizing three pig carcasses.

Phase 1

In the first phase, three pig carcasses, weighing between 29.5-32.2 kg (65-71 lbs.) were staked in three different locations based on those frequently encountered by OCSO Marine Unit: deep (approximately 7 m) with a flat, sandy bottom surface, shallow (approximately 1.5 m) with vegetation on the bottom surface, and mid-range (approximately 3.5 m) with a flat bottom surface surrounded vegetation, to investigate the effect of terrain on the visibility of features using side-scan sonar. Figure 11 shows the location of each pig within the lake, and the depth is

marked in Table 5. The pig carcasses in this portion were humanely euthanized and obtained from Florida Hospital Nicholson Center for Surgical Advancement, where they had utilized for training in robotic surgery. Prior to submersion in this research, the pig carcasses were frozen at 0^{o}F for 48 hours, and then thawed at room temperature for 72 hours. Between 5 and 11 days, one of the pig carcasses (1C) had pulled free from the stake and had to be relocated and reattached to the bottom surface. A half cinder block was employed in place of the hurricane ground stakes to secure the pig carcass to the bottom surface.

Table 5: Detailed information on each pig carcass for Phase 1

Submersion Date	**Pig Weight (kg/lbs.)**	**Depth (m)**	**Scenario**	**Designation**
10/31/2011	29.5/65	7.31	Sandy	1A
10/31/2011	31.8/70	1.52	In vegetation	1B
10/31/2011	32.2/71	3.66/7.47	Surrounded by vegetation; then sandy	1C

Figure 11: Research site with location of pig carcasses for Phase 1 marked; $1C_2$ is the secondary location of $1C_1$

Phase 2

The second phase consisted of three pigs, weighing between 51.3-54.4 kg (113-120 lbs.). Larger pig carcasses were employed in this phase to assess the difference between the two sizes, as well as more closely represent a medium-sized human. The pig carcasses for this phase were

humanely euthanized and obtained from a local pig farm. In Phase 2, the pig carcasses were all staked in a similar scenario to investigate the time interval in which side-scan sonar can discern a submerged body. However, between 7 and 11 days submerged, all three pig carcasses had pulled free of the stakes and were floating on the lake surface. The pig carcasses were reattached to the bottom surface using three half cinder blocks per pig carcass. As cinder blocks had not affected the first phase of research, they were again employed in this phase. Figure 12 shows the location of each pig carcass from the beginning of this phase, and Figure 13 shows the location of each pig carcass after they were reattached to the lake bottom.

Table 6: Detailed information on each pig carcass for Phase 2

Submersion Date	**Pig Weight (kg/lbs.)**	**Depth (m)**	**Scenario**	**Designation**
01/27/2012	54.4/120	7.47	Sandy	2A
01/27/2012	53.1/117	7.47	Sandy	2B
01/27/2012	51.3/113	7.31	Sandy	2C

Figure 12: Research site with location of pig carcasses for the first part of Phase 2 marked

Figure 13: Research site with location of pig carcasses for Phase 2 marked after they were returned to the lake bottom on February 7, 2012

Data Collection

A Centurion Sea Scan dual frequency side-scan sonar towfish was employed for this study (Figure 2). This sonar system received the second highest overall score from U.S. Department of Homeland Security's System Assessment and Validation for Emergency

Responders (System Assessment and Validation for Emergency Responders, 2009) based on its affordability, ease of use, portability, easy system setup, resilient equipment, and readable screen. The towfish could operate at either 900 kHz or 1800 kHz, and a pontoon boat was utilized to tow the side-scan sonar (Figure 3). The towfish was connected to the control unit via a cable, and the towfish was towed from the front of the boat (Figure 1). Additionally, a GPS unit was connected to the sonar control unit to establish the GPS coordinates of the towfish.

On October 31, 2011, divers investigated the lake bottom to determine the optimal locations for each pig carcass. Three locations were selected based on the scenarios frequently encountered by OCSO Marine Unit, such as in a shallow area with vegetation, near vegetation, and on a flat, clear bottom. After selecting locations, the pigs were tied with metallic cable to hurricane ground stakes, and divers secured the stakes into the ground at the correct location. The geographical coordinates were noted using the GPS system on the boat (Figure 3). After each pig carcass was staked to the bottom, side-scan sonar surveys were performed to locate the pig carcasses. The transects were collected in two directions. Transects for Pig 1A were collected in the north-south and south-north directions while transects for Pig 1B and Pig $1C_1$ were collected in the east-west and west-east directions. After relocation, transects for Pig $1C_2$ were collected in the north-south and south-north directions (Figure 14). Perpendicular transects were not possible due to the width of the lake in this area and the location of the pig carcasses. In Phase 1, the best parameters for a body search were investigated. Therefore, transects were conducted at both the 10 m range and the 20 m range. Additionally, both the 900 kHz frequency and the 1800 kHz frequency were utilized to provide a preliminary basis for comparison of the frequency. Data collection occurred approximately every week for three weeks depending on the schedules of OCSO Marine Unit. After three weeks, OCSO Marine Unit was unable to continue

data collection until January 2012. However, the pig carcasses were scanned on January 27, 2012 before the skeletal elements were recovered.

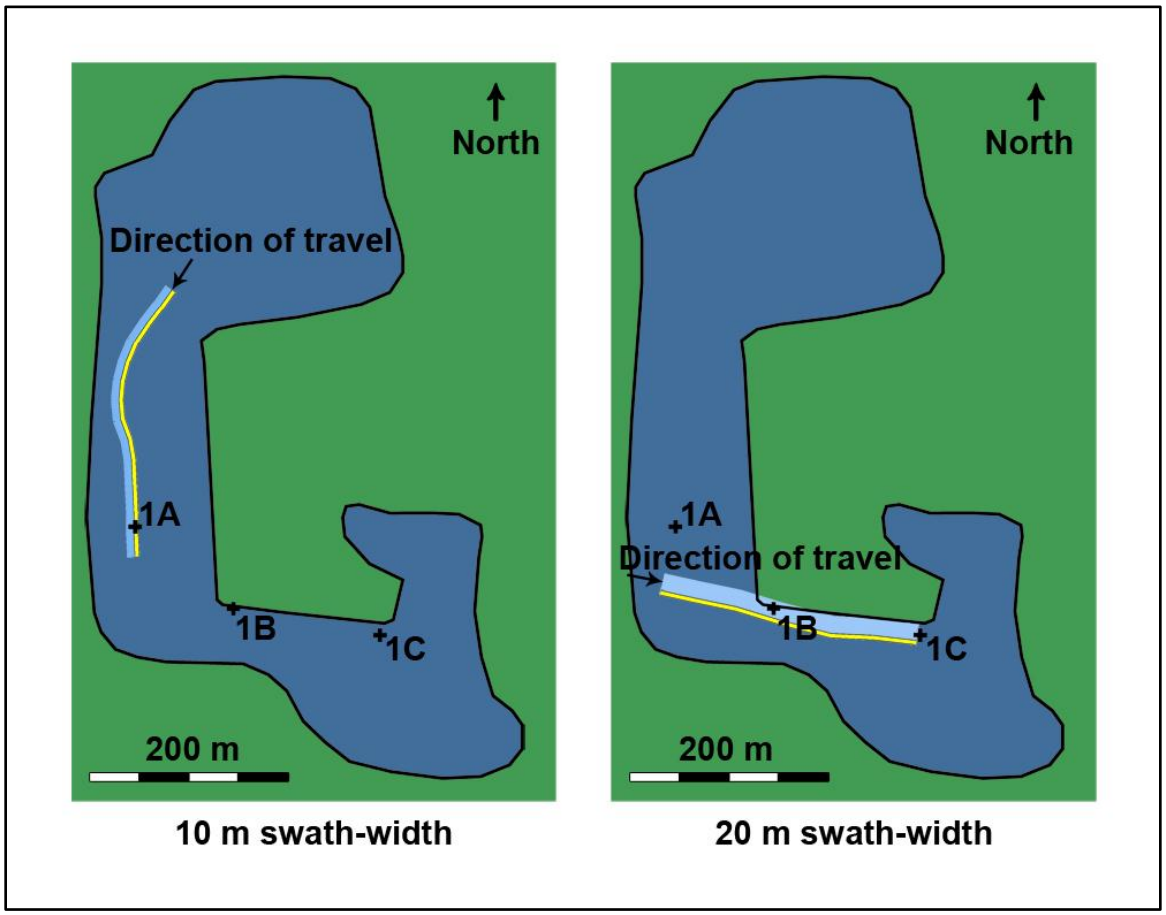

Figure 14: Sample Transects from November 1, 2011. The light blue signifies the swath width; the yellow signifies the path of the towfish.

For Phase 2, the three pig carcasses were staked along the same transect in the north-south direction (Figure 12). The pig carcasses were tied to the hurricane ground stake in the same manner as Phase 1, and divers staked the pig carcasses to firm ground. This phase investigated the appropriate frequency for searches, and therefore, a 20 m swath width was employed, but transects were collected at both frequencies. Again, each frequency included a north-south transect and a south-north transect (Figure 15).

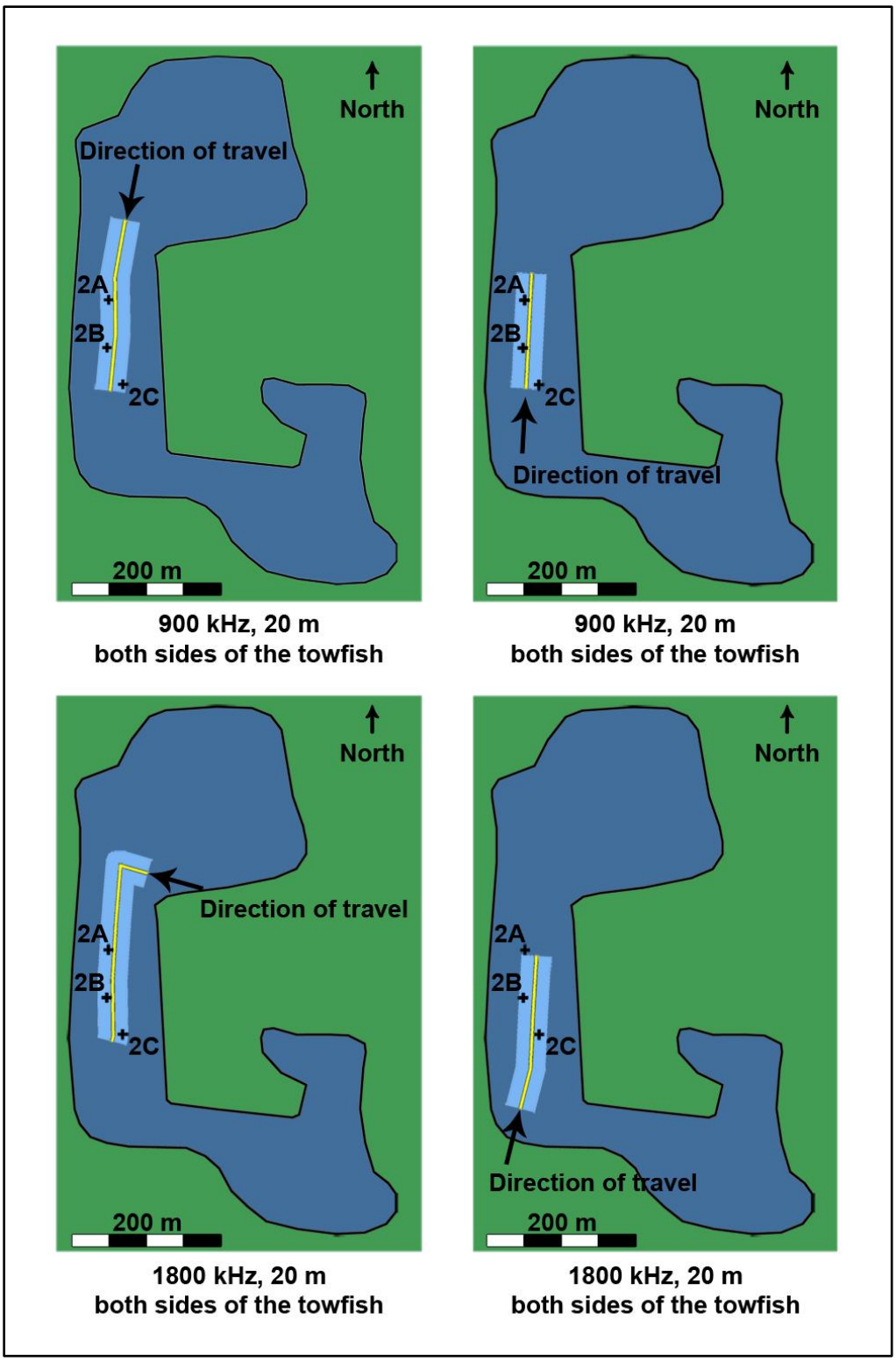

Figure 15: Transects from February 16, 2012 of Phase 2. Light blue signifies the swath width, and yellow signifies the path of the towfish.

To monitor the decomposition of pig carcasses, divers were utilized to photograph and describe the pig carcasses at each data collection. They were not deployed February 7 since each pig carcass was on the surface, and divers were not available February 16. Additionally, visibility was poor on April 17, and therefore underwater pictures were not taken, but the remains were removed from the lake and the state of decomposition was observed.

Identifying the location of the pig carcass with side-scan sonar was paramount to this research. The pig carcasses were identified by several features: a contrasting area in the shape of a pig, a shadow in the shape of a pig, a feature with a line connecting it to the shadow (signifying the cable connecting the pig carcass to the bottom surface), or a feature with a disconnected shadow (signifying the feature was floating). A representative of each parameter was scored to determine the discernibility of the pig carcass. When scoring a sonar image, several features were analyzed: the size and morphology of the shadow, the location of the shadow in relation to the feature since the pig carcass was floating, and the size and morphology of the features present. The pig carcass received a score of "excellent" if the pig carcass was easily discernible or if the shadow of the pig carcass could be discernible as a pig. A score of "good" was given to images in which the features were not easily identified as a pig carcass, but were distinct from the surroundings enough to be determined as a feature. Easily discernible was defined in several ways: a distinct shadow, a feature and shadow separated from the bottom surface, since the pig carcass was floating, or a tight cluster of features. A score of "poor" was given to the image if there was a possible, but indistinct shadow or if the feature could not be definitively identified as the pig carcass, including a lack of a consolidated feature with little to no shadow. A score of "none" was given to the pig carcass if it was not visible on the image. When performing a submerged body search, features with a score of "excellent" or "good" should be marked with a

buoy and further investigated by the divers. However, if there are no features scored as "excellent" or "good," then features scored as "poor" should be marked by a buoy and investigated by divers.

Results

Phase 1

The scores for Phase 1 are listed in Table 7, Table 8, and Table 9. Additionally, for Phase 1, each transect was scored to determine if the pig carcass was within range or not within range (Table 10). Pig 1A was discernible periodically throughout the data collection period (Figure 17, Figure 18, and Figure 19). Pig 1B was indiscernible throughout the data collection period (Figure 20). Pig 1C was discernible initially and again after it was relocated (Figure 21, Figure 22, and Figure 23). Scored sonar images are included in the appendices (APPENDIX B: SONAR IMAGES FROM PIG 1A, APPENDIX C: SONAR IMAGES FROM PIG 1B, and APPENDIX D: SONAR IMAGES FROM PIG 1C)

Table 7: Scoring table for Pig 1A of Phase 1

Date	Frequency (kHz)	Swath width (m)	File	Visibility
10/31/2011	1800	10	31Oct142	Good
10/31/2011	1800	20	31Oct134	None
11/01/2011	900	10	01Nov027	Poor
11/01/2011	1800	10	01Nov049	Poor
11/04/2011	900	10	04Nov006	None
11/04/2011	1800	10	04Nov041	None
11/04/2011	1800	20	04Nov052	Poor
11/11/2011	900	10	11Nov011	Poor
11/11/2011	900	20	11Nov060	Good
11/11/2011	1800	10	11Nov026	Poor
11/11/2011	1800	20	11Nov069	Good
11/14/2011	900	20	14Nov005	Poor
11/14/2011	1800	20	14Nov027	Poor
11/18/2011	900	10	18Nov123	Poor
11/18/2011	900	20	18Nov012	Poor
11/18/2011	1800	10	18Nov029	Good
11/18/2011	1800	20	18Nov031	Good
01/27/2012	900	20	27Jan009	Poor

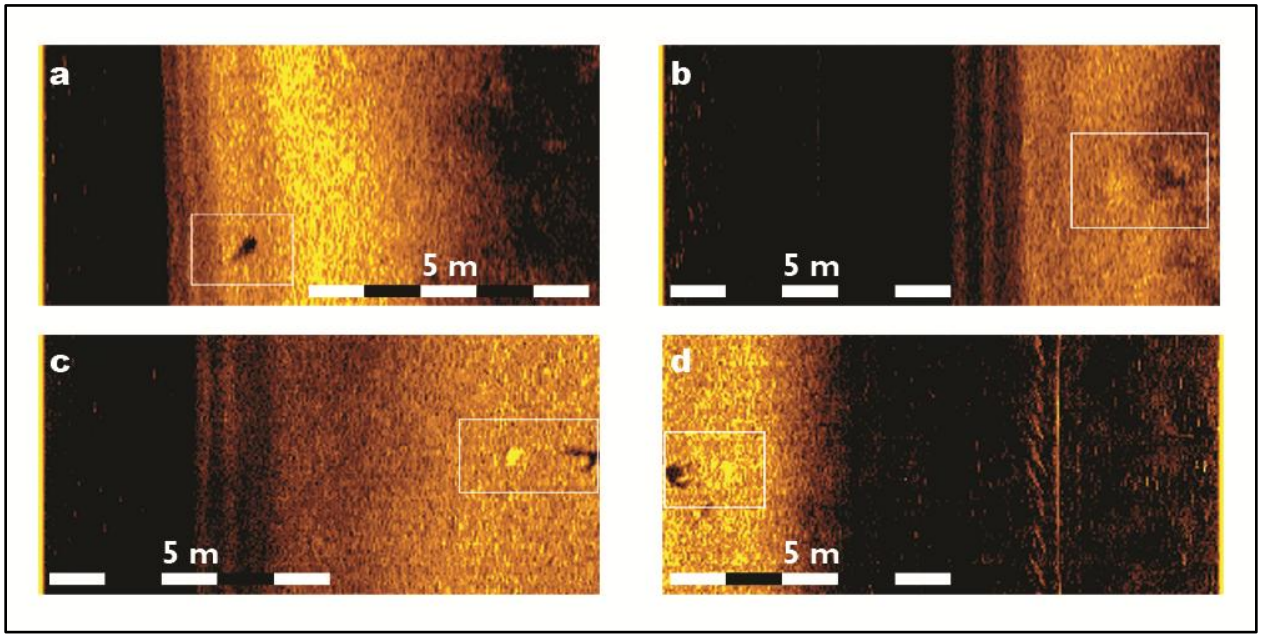

Figure 16: Images from Pig 1A, 900 kHz, 10 m swath width: a) November 1, 2011; b) November 4, 2011; c) November 11, 2011; d) November 18, 2011.

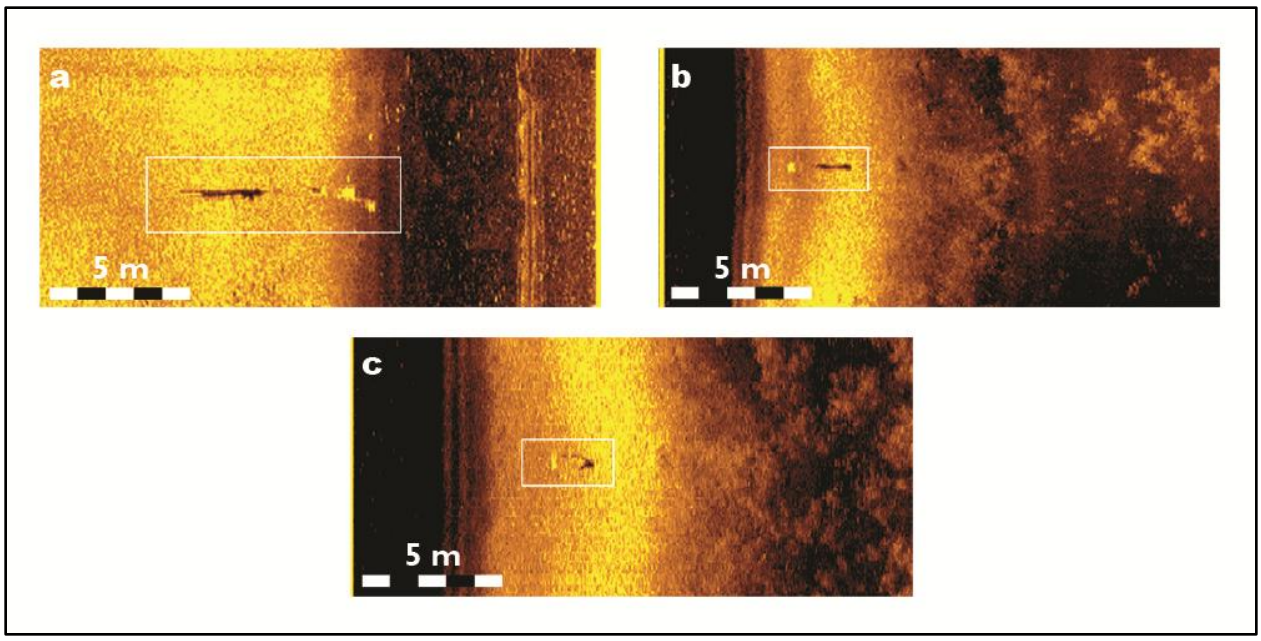

Figure 17: Sonar images from Pig 1A, 900 kHz, 20 m swath width: a) November 11, 2011; b) November 14, 2011; c) November 18, 2011.

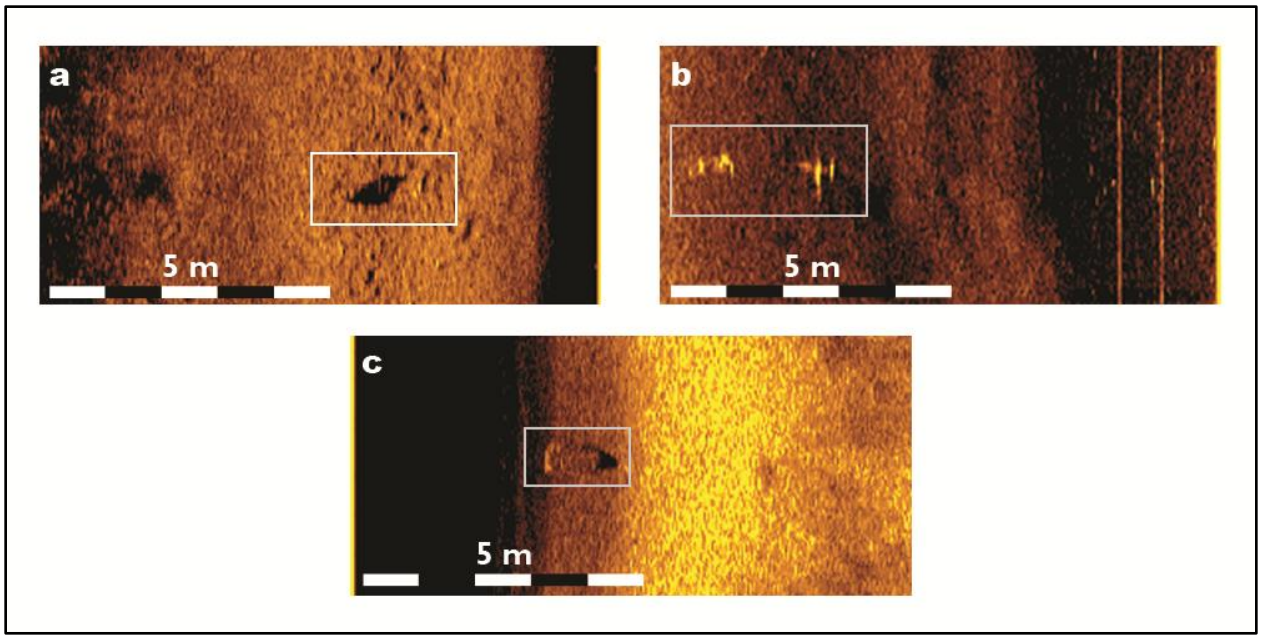

Figure 18: Sonar images from Pig 1A, 1800 kHz, 10 m swath width: a) October 31, 2011; b) November 11, 2011; c) November 18, 2011.

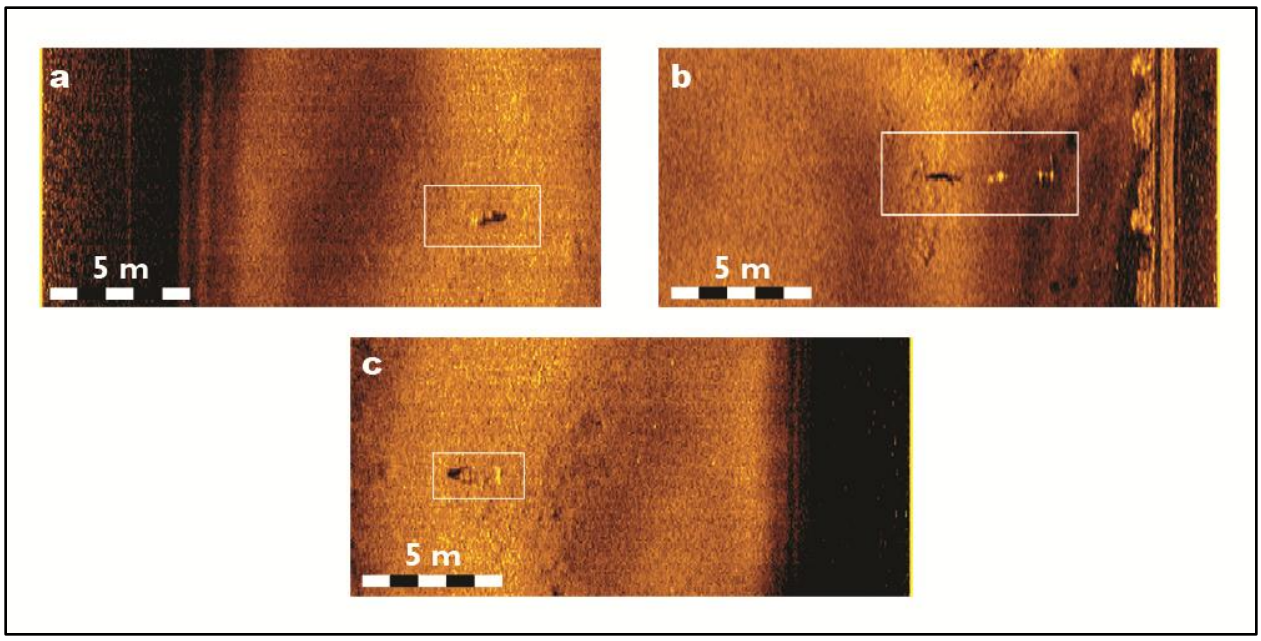

Figure 19: Sonar images from Pig 1A, 1800 kHz, 20 m swath width: a) November 4, 2011; b) November 11, 2011; c) November 18, 2011.

Table 8: Scoring table for Pig 1B of Phase 1

Date	Frequency (kHz)	Swath width (m)	File	Visibility
10/31/2011	900	20	31Oct114	None
10/31/2011	1800	20	31Oct164	None
11/01/2011	900	10	01Nov088	None
11/01/2011	900	20	01Nov136	None
11/01/2011	1800	10	01Nov119	None
11/04/2011	900	10	04Nov076	None
11/04/2011	1800	10	04Nov113	None
11/04/2011	1800	20	04Nov132	None
11/11/2011	900	10	11Nov048	None
11/11/2011	1800	10	11Nov054	None
11/11/2011	1800	20	11Nov057	None
11/14/2011	900	20	14Nov094	None
11/14/2011	1800	10	14Nov099	None
11/14/2011	1800	20	14Nov087	None
11/18/2011	900	10	18Nov153	Poor
11/18/2011	1800	10	18Nov142	None
11/18/2011	1800	20	18Nov133	None
01/27/2012	1800	20	27Jan021	None

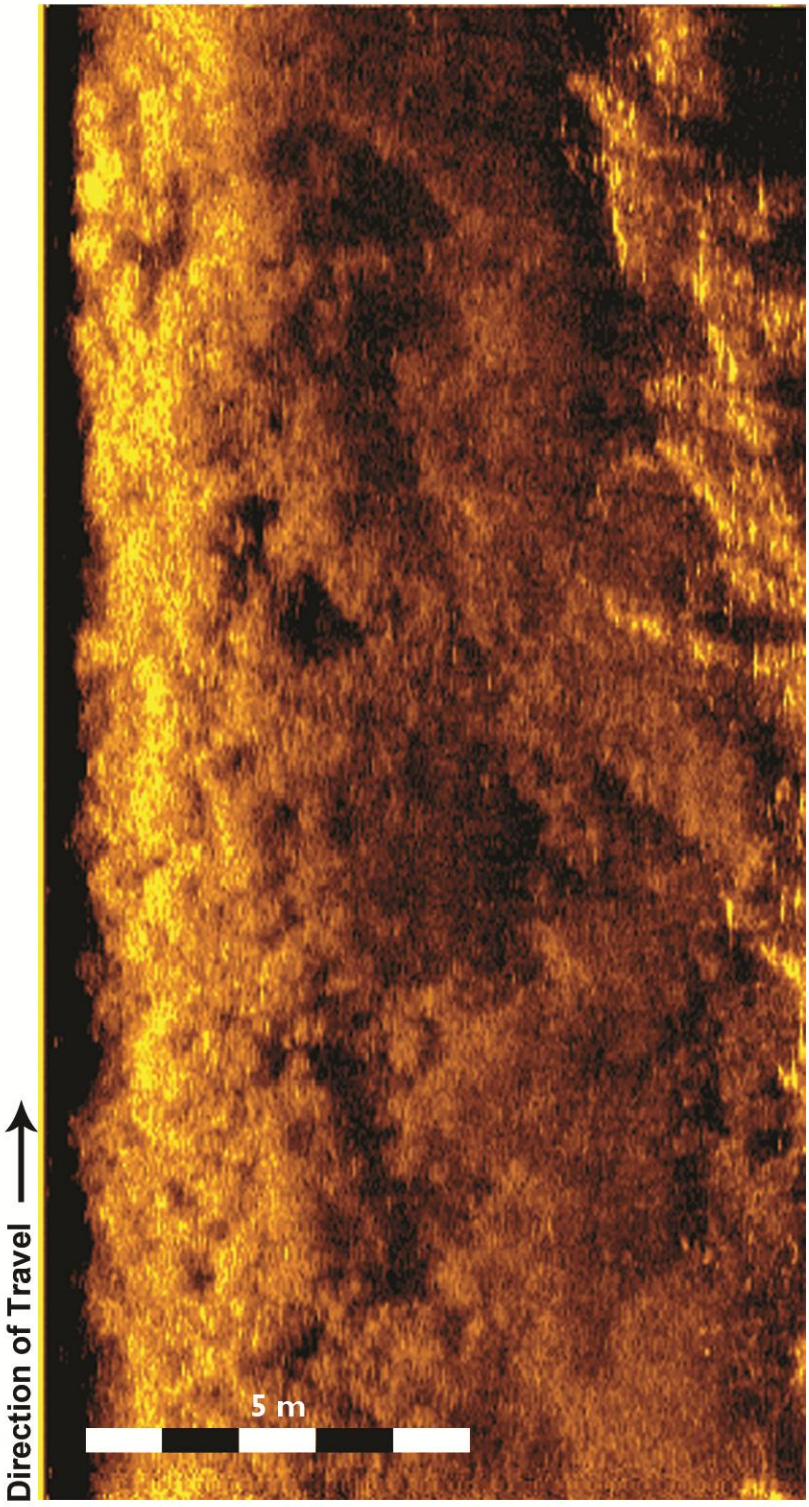

Figure 20: Sonar image of pig carcass 1B from November 1, 2011 collected with 900 kHz frequency, 10 m swath-with, and acoustic signals transmitted out of the right side of the towfish. The pig carcass was not detected in the vegetation.

Table 9: Scoring table for Pig 1C of Phase 1. The pig carcass was relocated on November 11, 2011.

Date	Frequency (kHz)	Swath width (m)	File	Visibility
10/31/2011	900	20	31Oct106	None
10/31/2011	1800	20	31Oct160	None
11/01/2011	900	10	01Nov100	None
11/01/2011	900	20	01Nov130	Good
11/01/2011	1800	10	01Nov126	None
11/04/2011	900	10	04Nov069	None
11/04/2011	1800	10	04Nov094	None
11/04/2011	1800	20	04Nov136	None
11/11/2011	900	10	11Nov059	Good
11/11/2011	1800	10	11Nov081	None
11/11/2011	1800	20	11Nov075	Poor
11/14/2011	900	20	14Nov078	Good
11/14/2011	1800	20	14Nov030	Good
11/18/2011	900	10	18Nov102	Poor
11/18/2011	1800	10	18Nov091	Poor
11/18/2011	1800	20	18Nov036	Good
01/27/2012	900	20	27Jan010	None

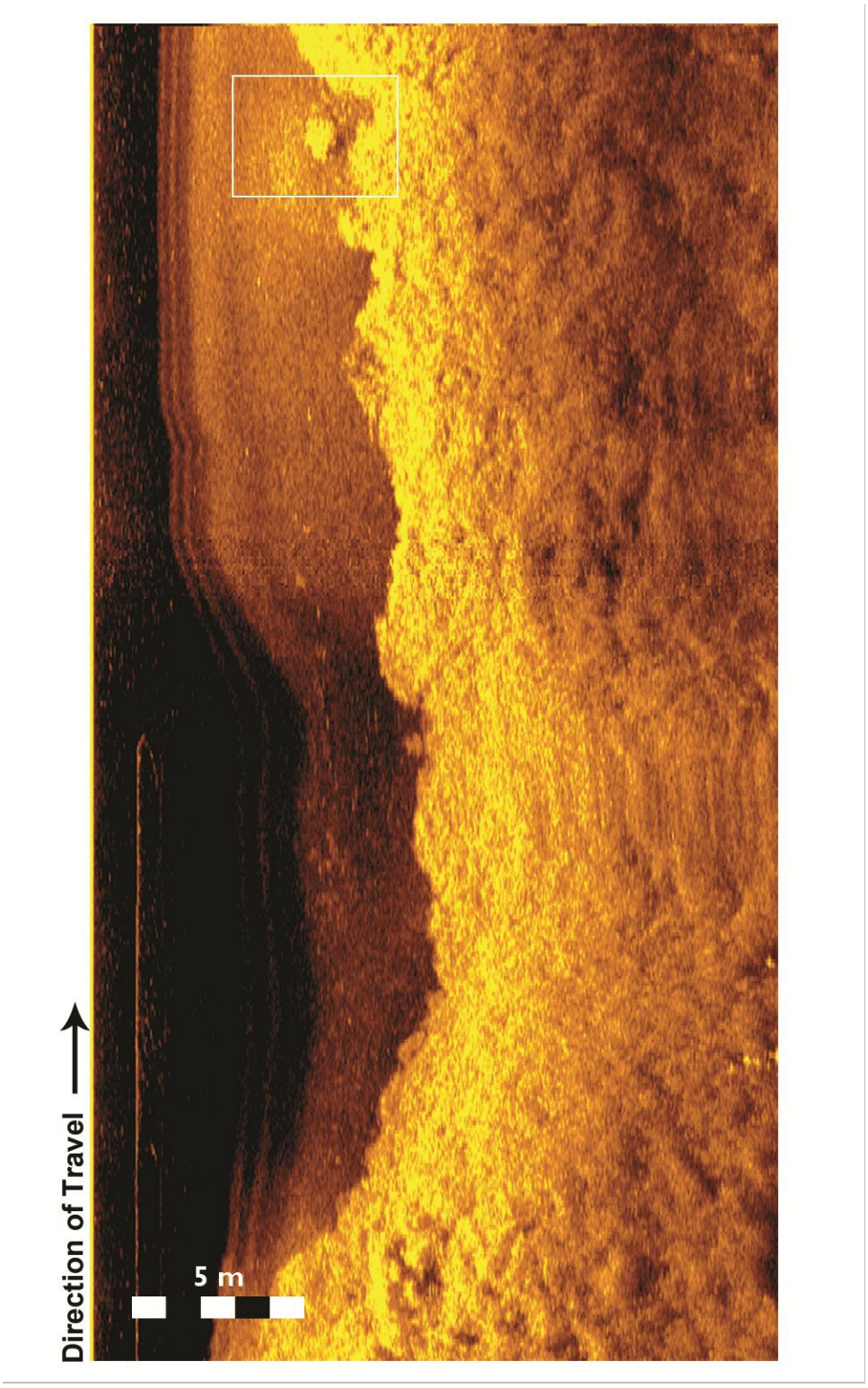

Figure 21: Sonar image of Pig 1C$_1$ collected with 1800 kHz frequency, 20 m swath width, and acoustic signals transmitted out of the right side of the towfish. The pig carcass was detected on the edge of the vegetation, but the shadow was likely obscured by the vegetation.

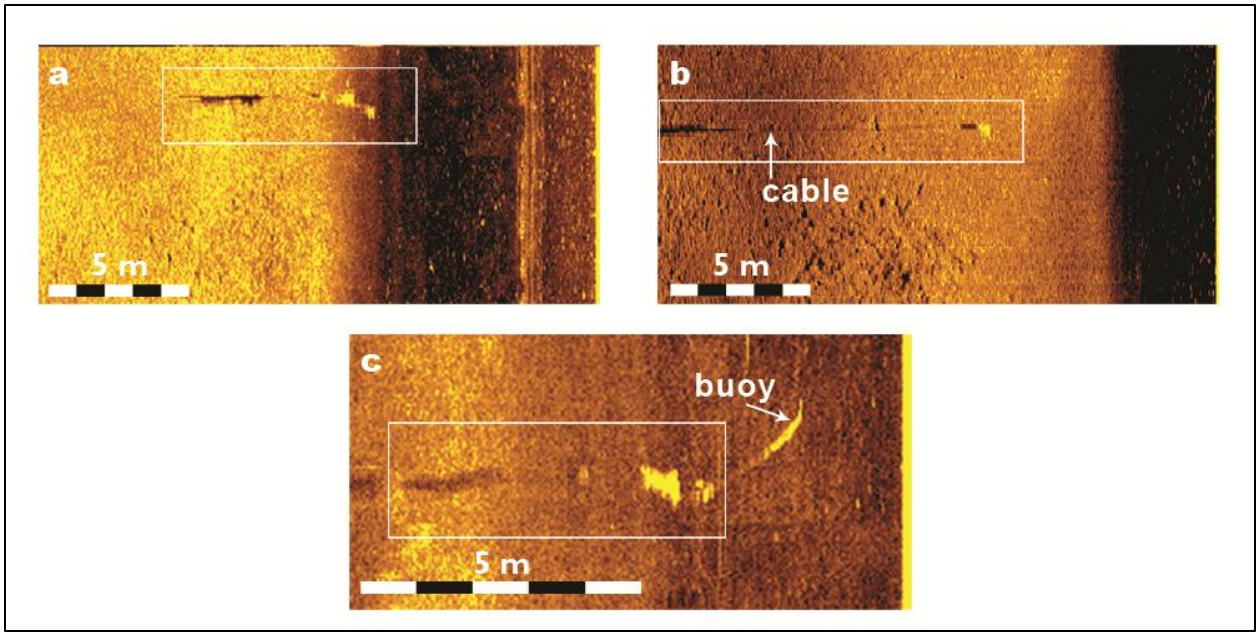

Figure 22: Sonar image of Pig 1C$_2$ at 900 kHz: a) November 11, 2011, 20 m swath width; b) November 14, 2011, 20 m swath width; c) November 18, 2011, 10 m swath width. Note that the cable affixing the carcass to the ground stake and the cable from the buoy marker were detected.

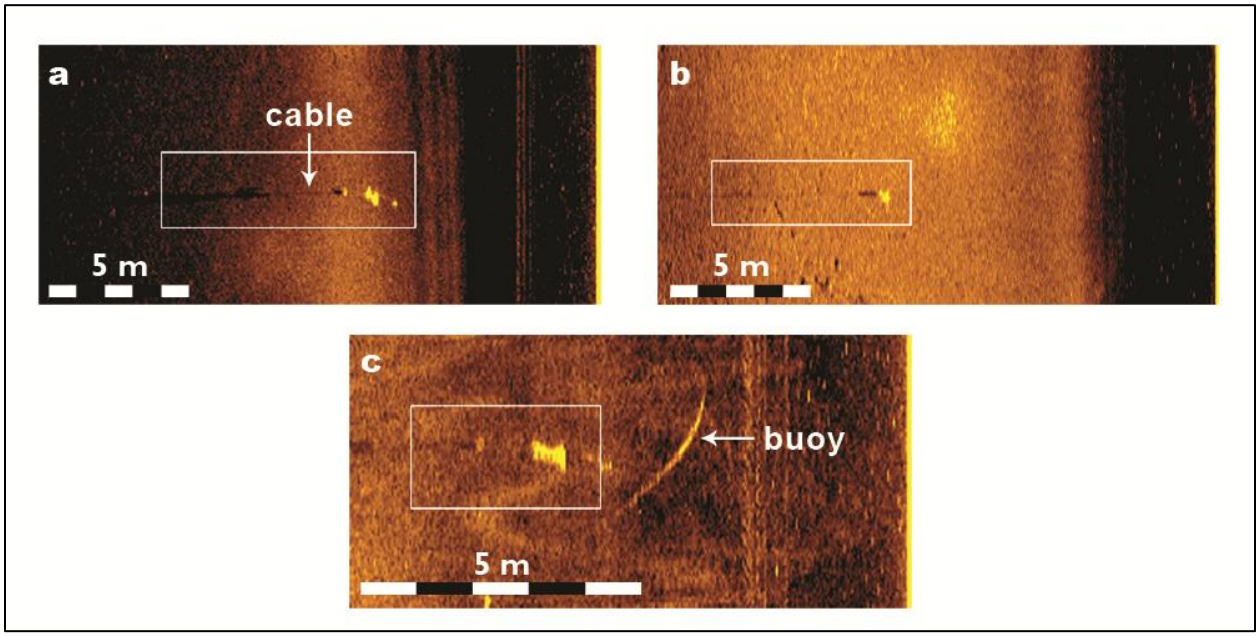

Figure 23: Sonar images from Pig 1C$_2$ at 1800 kHz: a) November 14, 2011, 20 m swath width; b) November 18, 2011, 20 m swath width; c) November 18, 2011, 10 m swath width. Note that the cable affixing the carcass to the ground stake and the cable from the buoy marker were detected.

Table 10: Out of range table

Date	Distance (m)	In Range	Out of range	Percent Out of range (%)
11/01/11	10	11	10	48
11/01/11	20	3	1	25
Total		*14*	*11*	*44*
11/04/11	10	8	6	43
11/04/11	20	5	1	17
Total		*13*	*7*	*35*
11/11/11	10	8	1	11
11/11/11	20	7	2	22
Total		*15*	*3*	*17*
11/14/11	10	1	0	0
11/14/11	20	21	13	38
Total		*22*	*13*	*37*
11/18/11	10	15	13	46
11/18/11	20	7	0	0
Total		*22*	*13*	*27*
Overall	10	44	30	41
	20	43	17	28
Total		*87*	*47*	*54*

Table 11: Overview of side-scan sonar imagery results for Phase 1

Pig	Overview of Side-scan Imagery Results
1A	Visibility increased over time interval, with the 20 m swath width having the best visibility
1B	Overall, this pig carcass was not visible, although one transect was able to possibly detect the pig carcass floating
$1C_1$	Poor to no visibility throughout the time interval
$1C_2$	Good visibility throughout the time interval, independent of frequency and swath width

In Phase 1, scenarios that could affect submerged body detection as well as the best parameters to detect a submerged body were investigated. Vegetation prevented the detection of Pig 1B throughout the time period, and Pig 1B was more scavenged during the data collection interval due to the shallow location and its close vicinity to shore. Divers encountered soft-shell turtles and fish scavenging the pig carcass after only one day of submersion. Additionally, Pig

1C was poorly detected in the beginning of Phase 1, even though it was on a flat area and only surrounded by vegetation. However, once Pig 1C was relocated to clear, flat, sandy bottom, it was easily discernible. Interestingly, Pig 1A was also located on clear, flat sandy bottom, and yet it was poorly visualized throughout data collection.

For Phase 1, the variable that most affected detection of the pig carcass was the swath width, since the pig carcass was outside the range of a number of transects. The size of the boat and environmental conditions also likely influenced whether the pig carcass was in range, as the pontoon boat was affected by windy conditions more than a smaller boat would be, and therefore, navigating within 10 m of the pig carcass on a windy day was more challenging than the 20 m swath width. Generally, the 20 m swath width was out of range less than the 10 m pig carcass.

Additionally when considering all the Phase 1 pig carcasses, of the two frequencies available, the pig carcasses were discernible 5 times with the 900 kHz and 7 times with the 1800 kHz frequency. While this is not a significant difference, it does suggest that the 1800 kHz frequency provides a better image than the 900 kHz frequency for small bodies, such as those of a child.

Phase 2

For Phase 2, larger pig carcasses were employed to investigate the effect of frequency on the discernibility of a feature, and to further investigate the effect of decomposition and disarticulation on the discernibility of a feature over time. If more than one image was collected for each parameter, the clearest image was scored. Table 12, Table 13, and Table 14 lists the scores for Phase 2. Figure 24 and Figure 25 are composite images of the scored transects from Pig 2A; Figure 26 and Figure 27 are composite images of the scored transects from Pig 2B; and

Figure 28 and Figure 29 are composite images of the scored transects from Pig 2C. Complete sonar images are included in the appendices (APPENDIX E: SONAR IMAGES FROM PIG 2A, APPENDIX F: SONAR IMAGES FROM PIG 2B and APPENDIX G: SONAR IMAGES FROM PIG 2C)

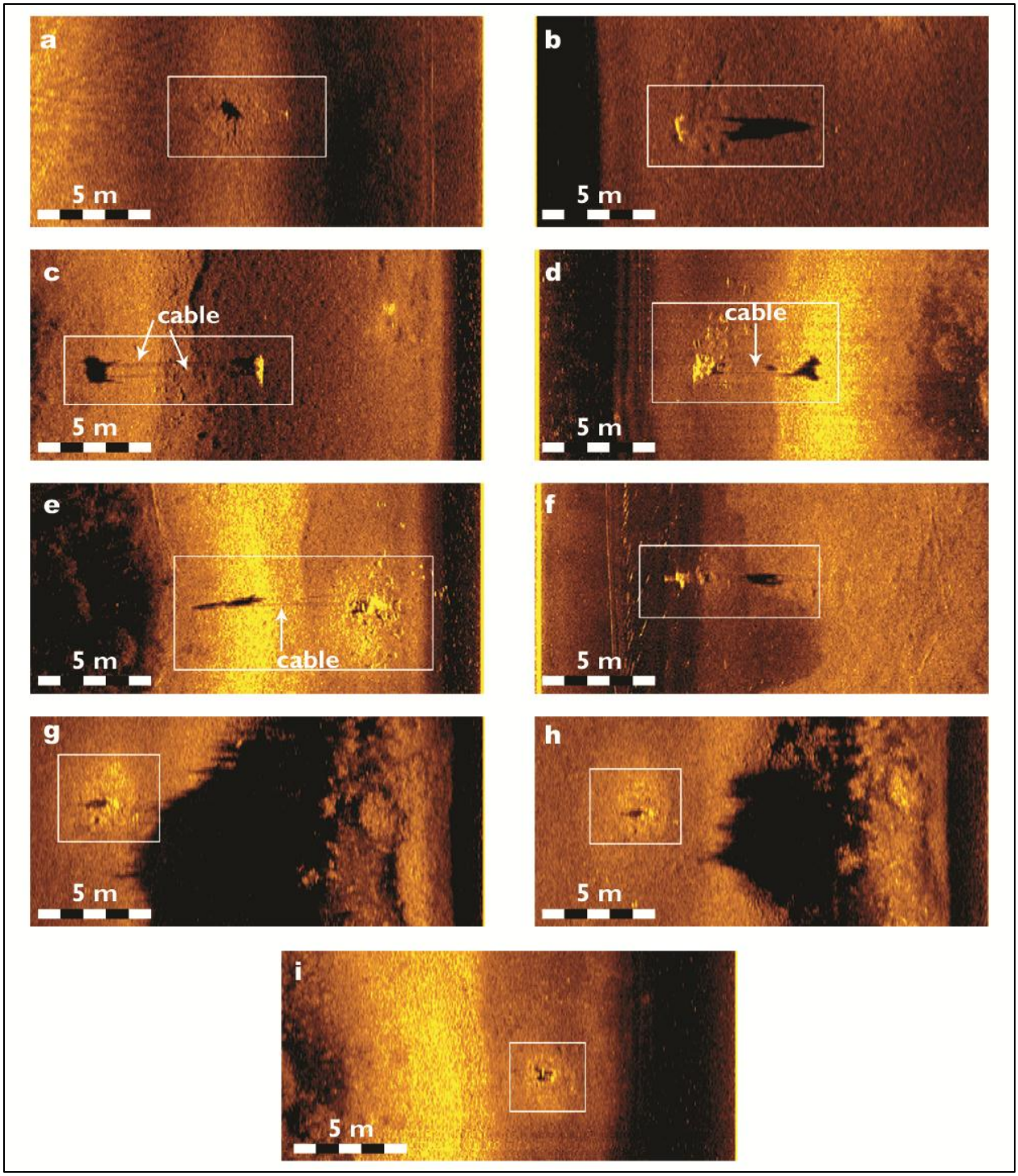

Figure 24: Sonar images from Pig 2A, 900 kHz, 20 m swath width: a) January 27, 2012; b) February 2, 2012; c) February 7, 2012; d) February 16, 2012; e) February 28, 2012; f) March 6, 2012; g) March 19, 2012; h) April 2, 2012; i) April 17, 2012. Note that the cables affixing the carcass to the half cinder blocks were detected.

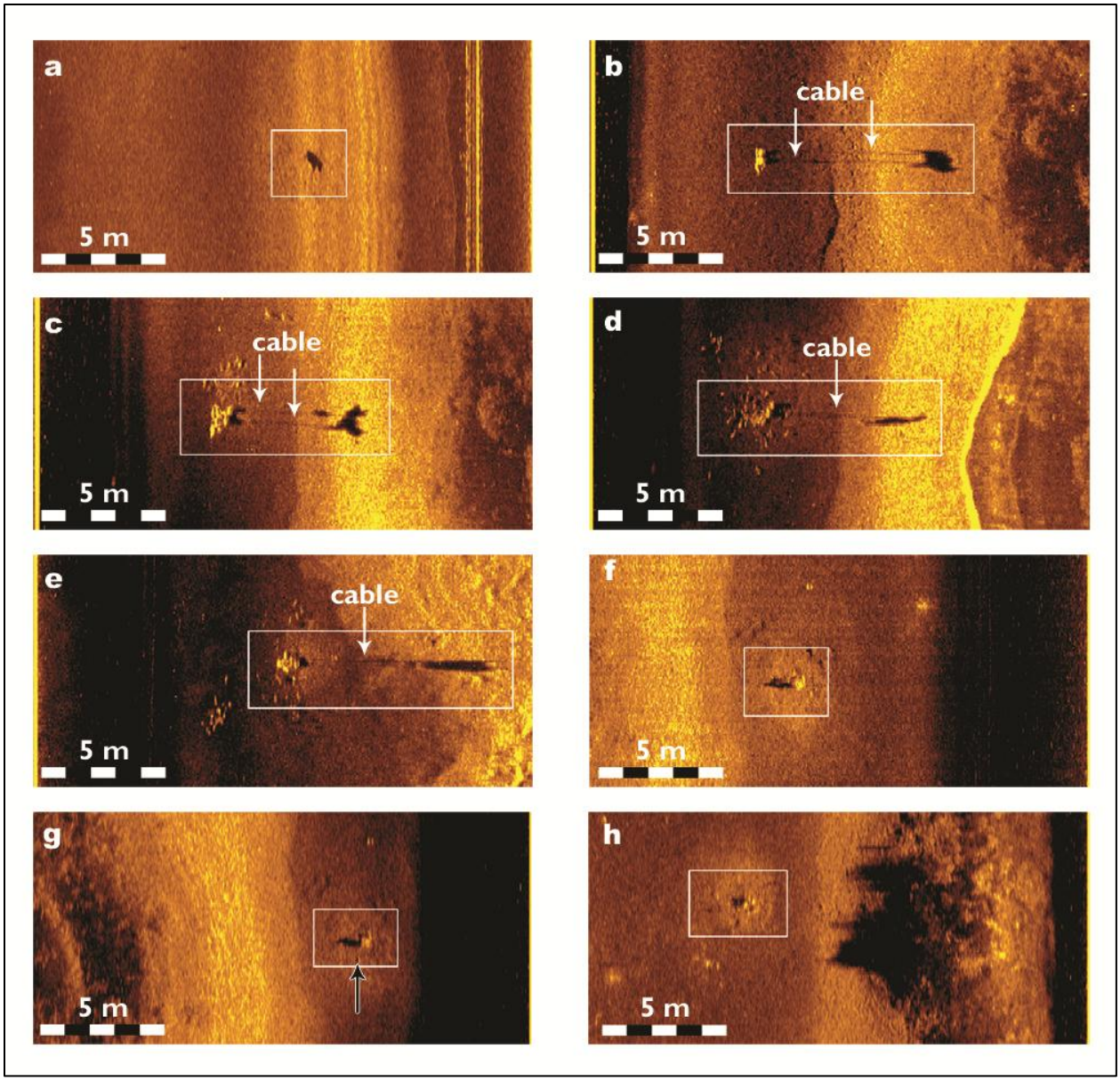

Figure 25: Sonar images from Pig 2A, 1800 kHz, 20 m swath width: a) February 2, 2012; b) February 7, 2012; c) February 16, 2012; d) February 28, 2012; e) March 6, 2012; f) March 19, 2012; g) April 2, 2012; h) April 17, 2012. January 27, 2012 not collected. Note that the cables affixing the carcass to the half cinder blocks were detected. Also, the black arrow (g) points to a possible half cinder block used as a weight.

Table 12: Scoring table for Pig 2A Phase 2

Date	Frequency (kHz)	Swath width (m)	File	Visibility
01/27/2012	900	20	27Jan046	Good
01/27/2012	1800	20	Not collected	
02/02/2012	900	20	02Feb018	Excellent
02/02/2012	1800	20	02Feb030	Excellent
02/07/2012	900	20	07Feb263	Excellent
02/07/2012	1800	20	07Feb273	Excellent
02/16/2012	900	20	16Feb005	Good
02/16/2012	1800	20	16Feb012	Good
02/28/2012	900	20	28Feb009	Good
02/28/2012	1800	20	28Feb011	Good
03/06/2012	900	20	06Mar012	Good
03/06/2012	1800	20	06Mar021	Good
03/19/2012	900	20	19Mar014	Poor
03/19/2012	1800	20	19Mar042	Poor
04/02/2012	900	20	02Apr008	Poor
04/02/2012	1800	20	02Apr033	Poor
04/17/2012	900	20	17Apr015	Poor
04/17/2012	1800	20	17Apr033	Poor

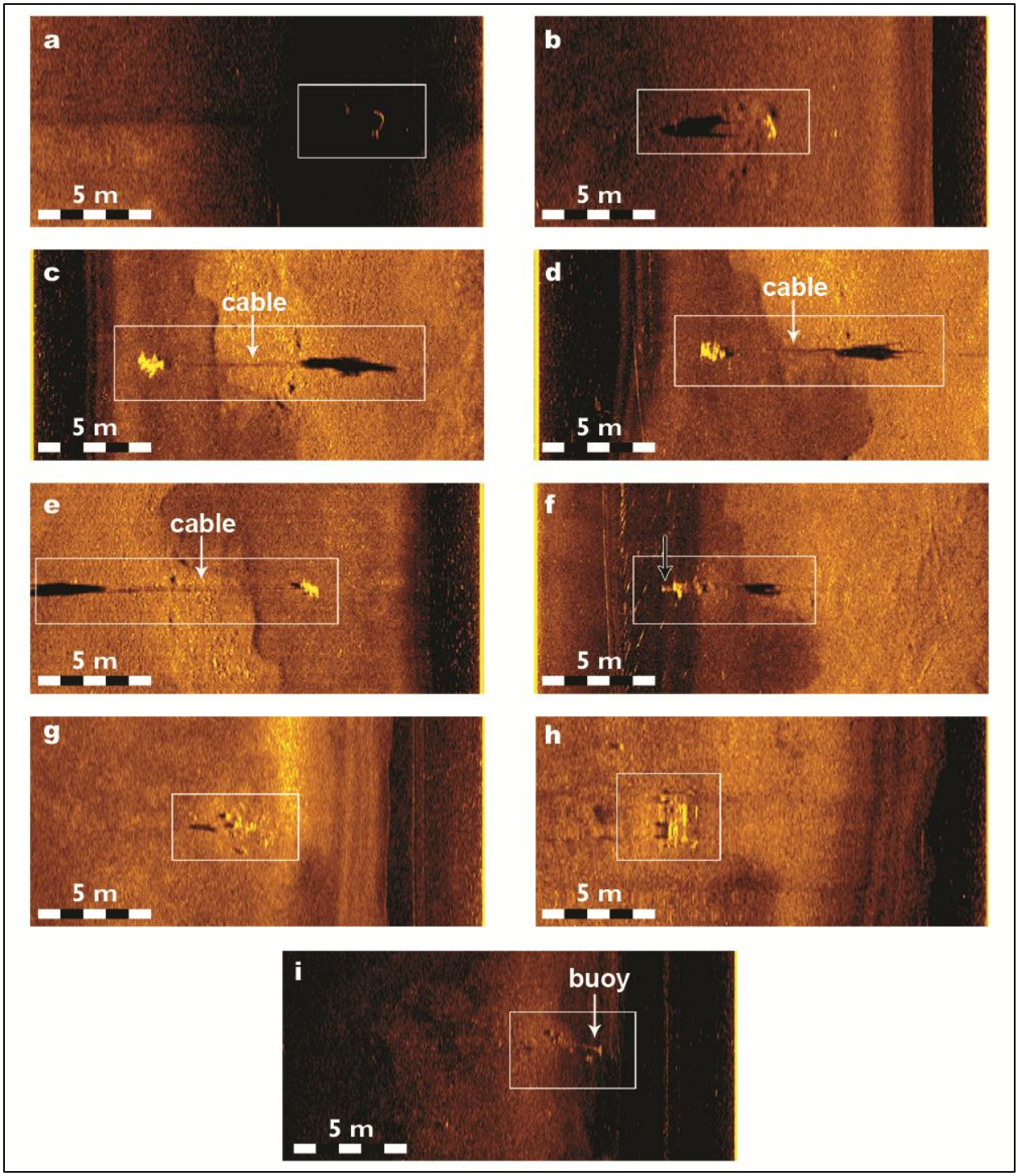

Figure 26: Sonar images from Pig 2B, 900 kHz, 20 m swath width: a) January 27, 2012; b) February 2, 2012; c) February 7, 2012; d) February 16, 2012; e) February 28, 2012; f) March 6, 2012; g) March 19, 2012; h) April 2, 2012; i) April 17, 2012. Note that the cables affixing the carcass to the half cinder blocks were detected. Also, the black arrow (f) points to a possible half cinder block used as a weight.

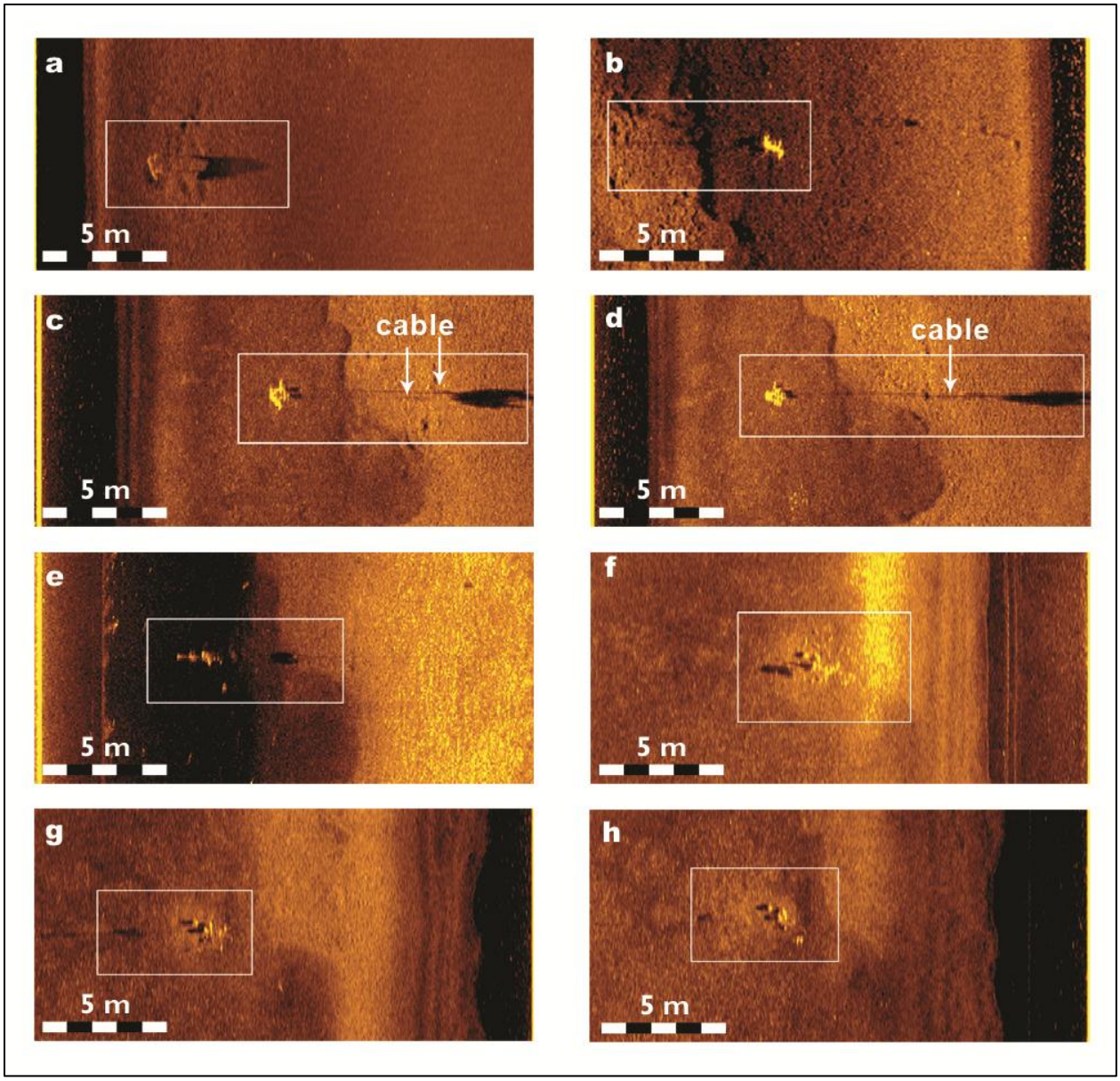

Figure 27: Sonar images from Pig 2B, 1800 kHz, 20 m swath width: a) February 2, 2012; b) February 7, 2012; c) February 16, 2012; d) February 28, 2012; e) March 6, 2012; f) March 19, 2012; g) April 2, 2012; h) April 17, 2012. January 27, 2012 data not collected for this frequency. Note that the cables affixing the carcass to the half cinder blocks were detected.

Table 13: Scoring table for Pig 2B, Phase 2

Date	Frequency (kHz)	Swath width (m)	File	Visibility
01/27/2012	900	20	27Jan047	Poor
01/27/2012	1800	20	Not collected	
02/02/2012	900	20	02Feb010	Excellent
02/02/2012	1800	20	02Feb042	Excellent
02/07/2012	900	20	07Feb266	Excellent
02/07/2012	1800	20	07Feb277	Good
02/16/2012	900	20	16Feb006	Good
02/16/2012	1800	20	16Feb013	Good
02/28/2012	900	20	28Feb008	Excellent
02/28/2012	1800	20	28Feb012	Good
03/06/2012	900	20	06Mar012	Good
03/06/2012	1800	20	06Mar006	Poor
03/19/2012	900	20	19Mar016	Poor
03/19/2012	1800	20	19Mar031	Poor
04/02/2012	900	20	02Apr010	Poor
04/02/2012	1800	20	02Apr024	Poor
04/17/2012	900	20	17Apr006	Poor
04/17/2012	1800	20	17Apr035	Poor

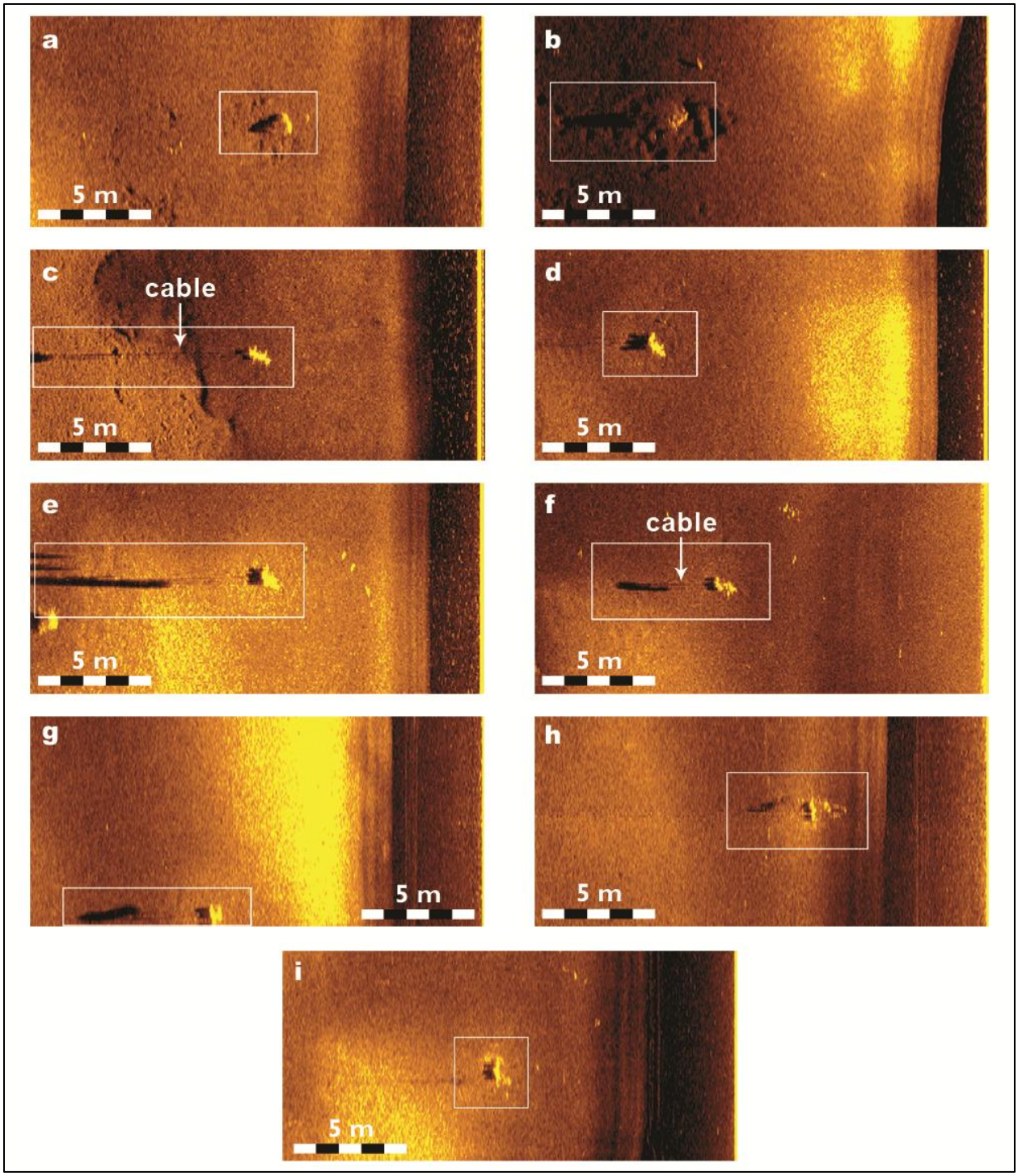

Figure 28: Sonar images from Pig 2C, 900 kHz, 20 m swath width: a) January 27, 2012; b) February 2, 2012; c) February 7, 2012; d) February 16, 2012; e) February 28, 2012; f) March 6, 2012; g) March 19, 2012; h) April 2, 2012; i) April 17, 2012. Note that the cables affixing the carcass to the half cinder blocks were detected.

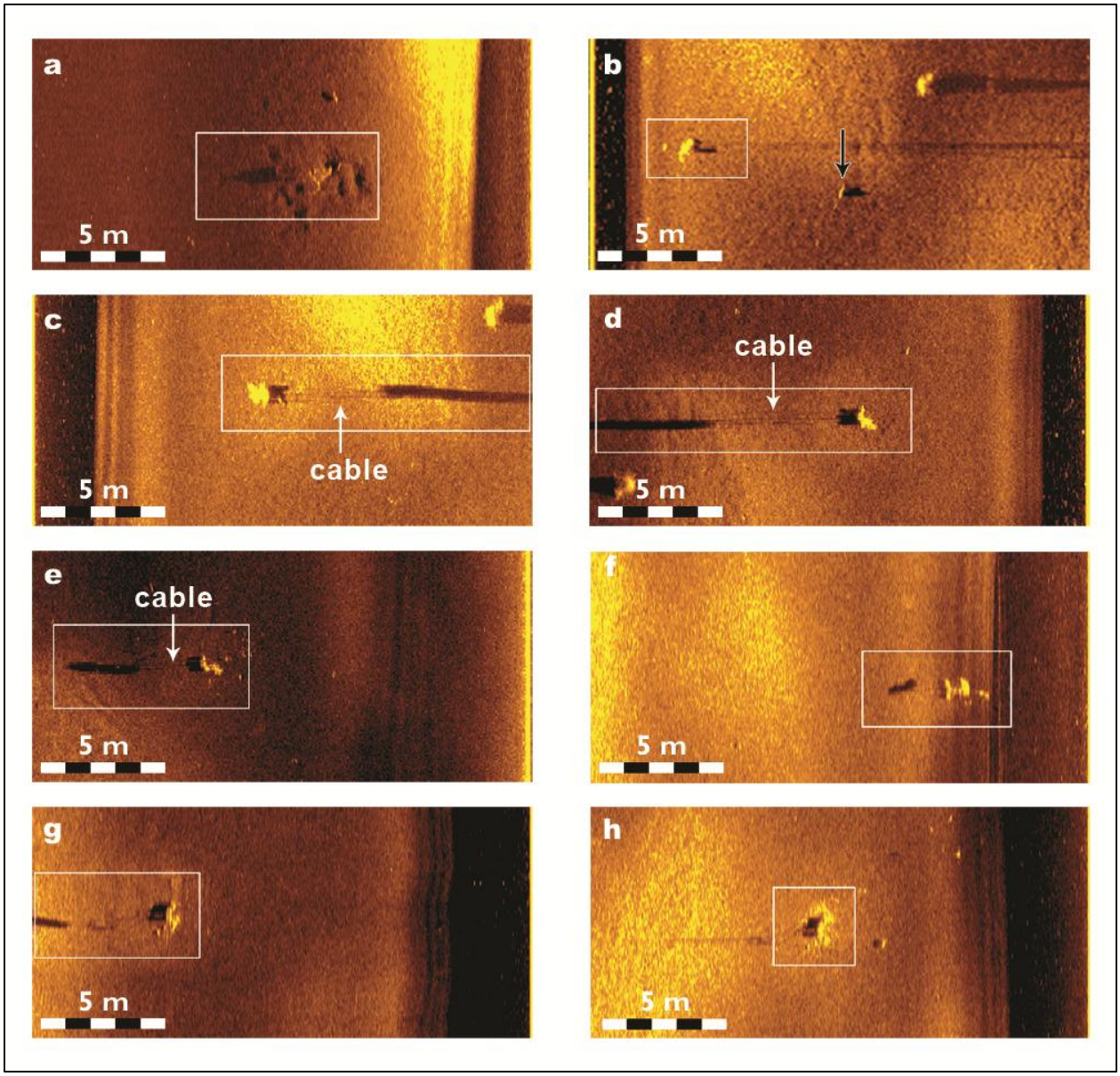

Figure 29: Images from Pig 2C, 1800 kHz, 20 m swath width: a) February 2, 2012; b) February 7, 2012; c) February 16, 2012; d) February 28, 2012; e) March 6, 2012; f) March 19, 2012; g) April 2, 2012; h) April 17, 2012. January 27, 2012 data not collected for this frequency. Note that the cables affixing the carcass to the half cinder blocks were detected.

Table 14: Scoring table for 2C, Phase 2

Date	Frequency (kHz)	Swath width (m)	File	Visibility
01/27/2012	900	20	27Jan049	Excellent
01/27/2012	1800	20	Not Collected	
02/02/2012	900	20	02Feb012	Excellent
02/02/2012	1800	20	02Feb034	Excellent
02/07/2012	900	20	07Feb262	Good
02/07/2012	1800	20	07Feb276	Good
02/16/2012	900	20	16Feb006	Good
02/16/2012	1800	20	16Feb015	Good
02/28/2012	900	20	28Feb005	Good
02/28/2012	1800	20	28Feb013	Good
03/06/2012	900	20	06Mar013	Good
03/06/2012	1800	20	06Mar006	Poor
03/19/2012	900	20	19Mar006	Poor
03/19/2012	1800	20	19Mar039	Poor
04/02/2012	900	20	02Apr014	Poor
04/02/2012	1800	20	02Apr026	Poor
04/17/2012	900	20	17Apr009	Poor
04/17/2012	1800	20	17Apr024	Poor

Table 15: Overview of side-scan imagery results for Phase 2

Pig	Overview of Side-scan Imagery Results
2A	Overall, this pig carcass was detected throughout the time interval, independent of frequency. However, after 52 days submerged, carcass scored as "poor" due to the lack of a consolidated feature and little to no shadow
2B	Overall, this pig carcass was detected throughout the time interval, independent of frequency. However, after 39 days submerged, carcass scored as "poor" with the 1800 kHz frequency and after 52 days scored as "poor" with the 900 kHz frequency due to a lack of consolidated feature and little to no shadow
2C	Overall, this pig carcass was detected throughout the time interval, independent of frequency. However, after 81 days submerged, carcass scored as "poor" due to the lack of a consolidated feature and little to no shadow.

In Phase 2, the pig carcasses were visible throughout the data collection. However, images with the 900 kHz frequency scored an 'excellent' 7 times, while images with the 1800 kHz frequency scored an 'excellent' only 4 times. While this is not a significant difference, it

does suggest that the 900 kHz frequency provided better quality images and increased the discernibility of the pig carcass.

Additionally, Phase 2 evaluated the decomposition of pig carcasses in shallow lakes and ponds in a humid, subtropical environment in Central Florida. Despite similar temperature and depth conditions, each pig progressed at a different rate, and different parts of the pig carcass were affected. Pig 2A decomposed faster than pigs 2B and 2C, although 2C was more heavily scavenged than the other two pigs. Pig 2B maintained buoyancy even after the spinal column was visible, while Pig 2C was heavily scavenged, but showed the least amount of decomposition. Interestingly, pigs 2A and 2B were barely affected by scavengers, even though all three pig carcasses were in similar environments.

Decomposition

In Phase 2, the decomposition of the pig carcass was a variable investigated. Therefore, it is important to document the changes in each pig carcass to correlate the decomposition rate with the visibility of the pig carcass. Figure 30, Figure 31, and Figure 32 demonstrate the decomposition process of each pig. Visibility was highly variable, and therefore, only the dates in which the pig carcass was visible are presented. On April 17, when the pig carcasses were recovered, the visibility was poor, but the remains were returned to the boat. On this date, the pig carcasses were skeletonized, although small amounts of tissue remained around the torso.

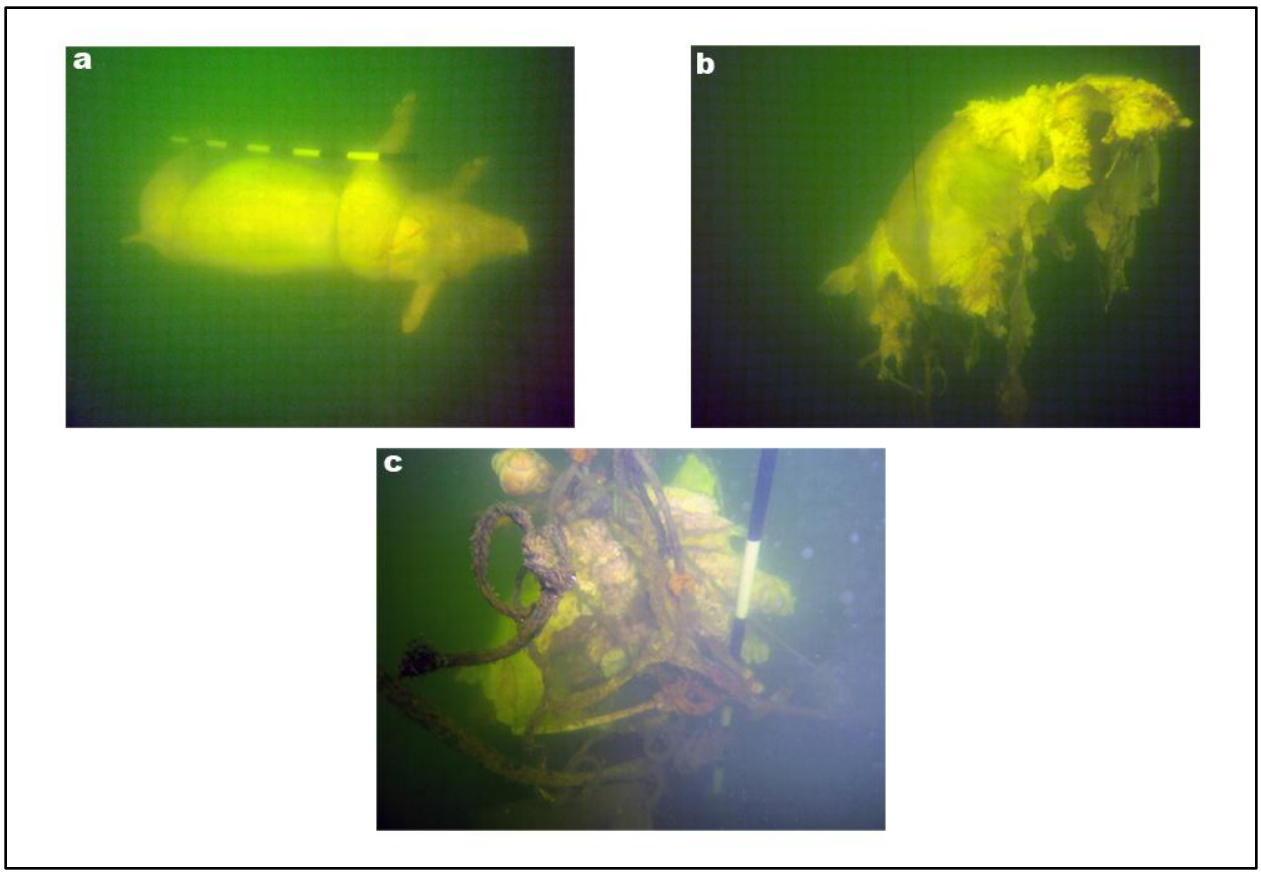

Figure 30: Progression of decomposition of pig carcass 2A over time: a) February 2, 2012; b) February 28, 2012; c) April 2, 2012. Note pig carcass is floating in representative images.

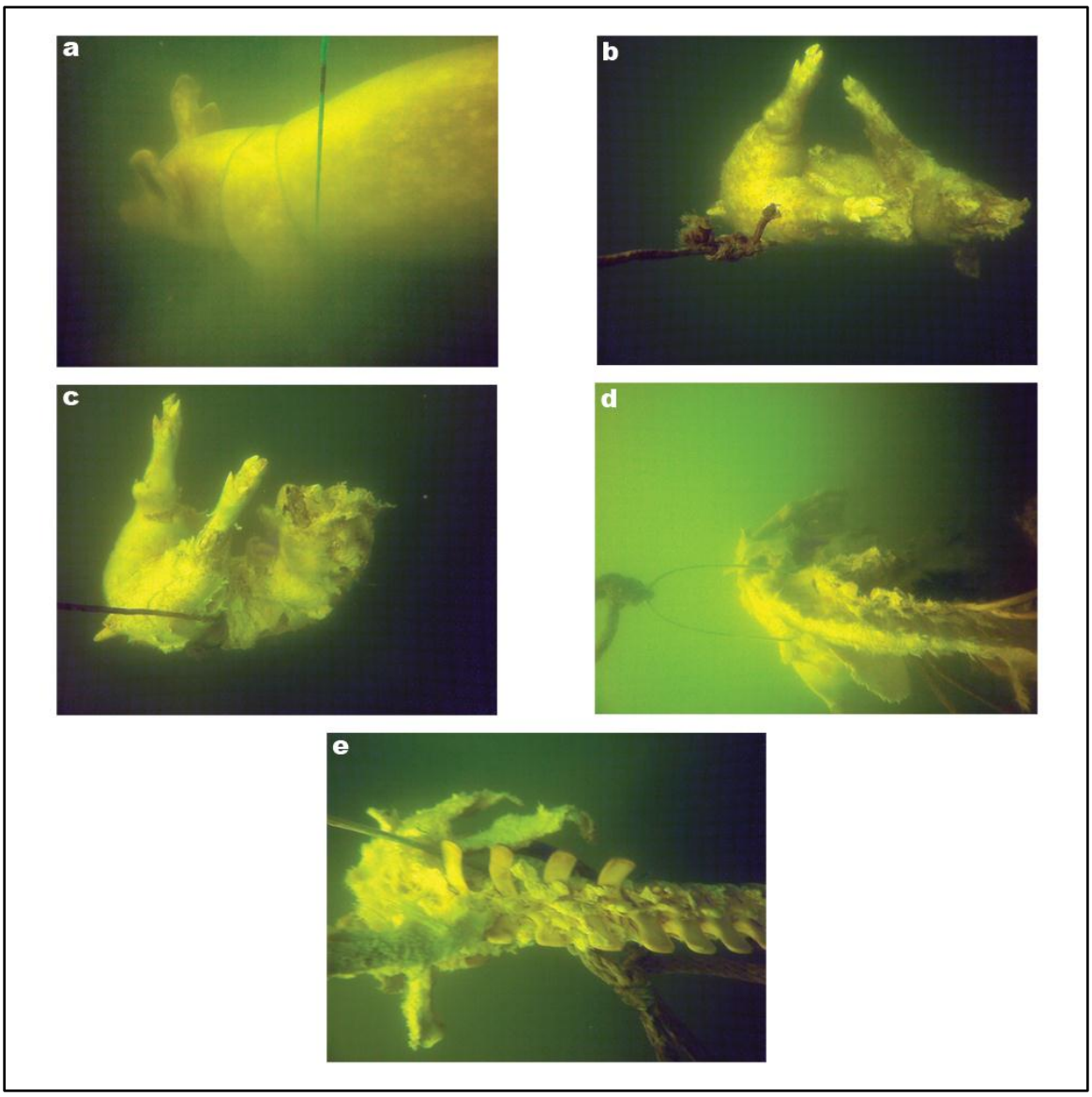

Figure 31: Progression of decomposition of pig carcass 2B over time: a) February 2, 2012; b) February 28, 2012; c) March 6, 2012; d) March 19, 2012; e) April 2, 2012. Note pig carcass is floating in representative images.

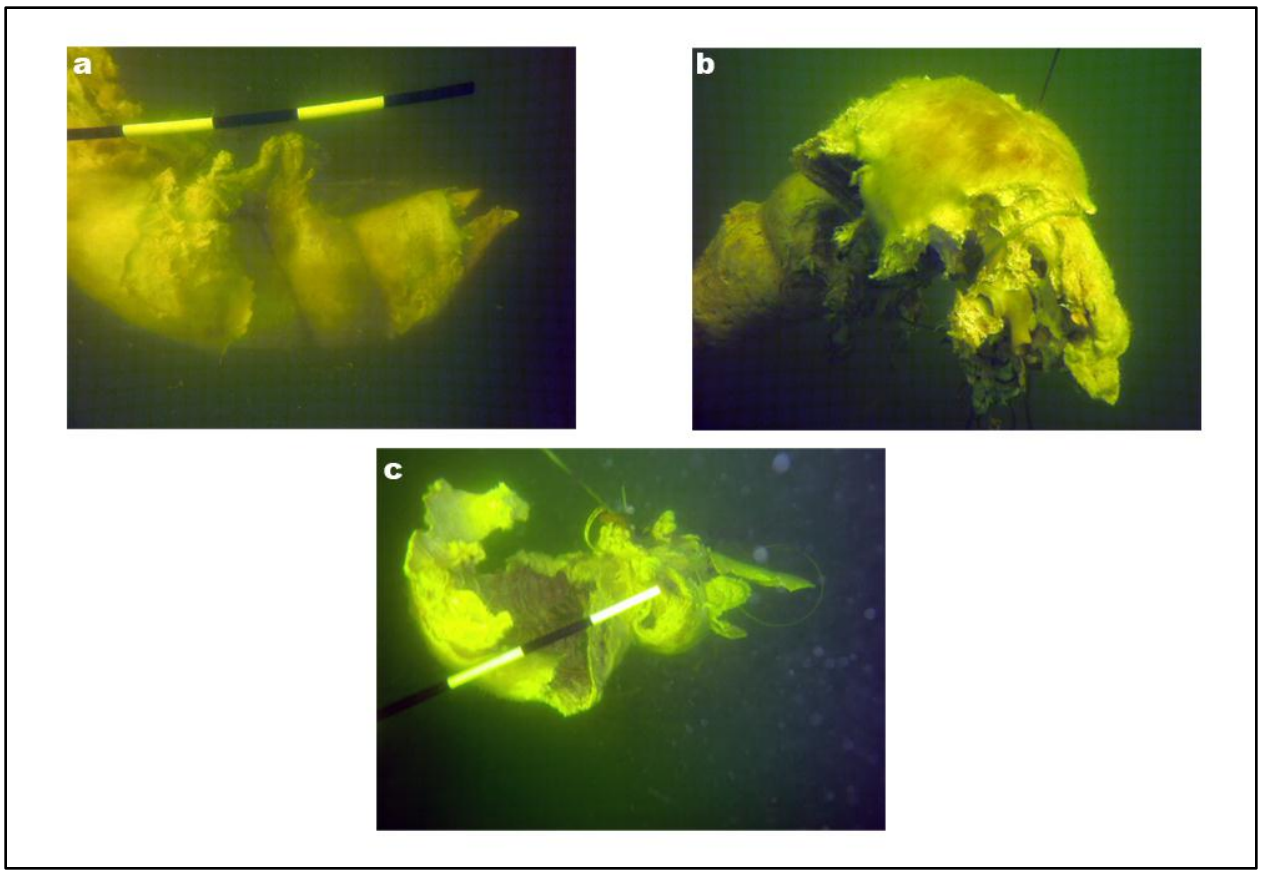

Figure 32: Progression of decomposition of pig carcass 2C over time: a) March 6, 2012; b) March 19, 2012; c) April 2, 2012. Note pig carcass is floating in representative images.

Despite the humid, subtropical environment, the decomposition of the pig carcasses followed Barrios and Wolff (Barrios and Wolff, 2011) stages of decomposition (Table 16). Pig carcasses 2A and 2C progressed at a similar rate, although diver observations noted that Pig 2A was decomposing slightly faster. A decomposition rate could be determined by evaluating diver observations and using photographs taken by the divers when possible. Each pig carcasses progressed through the stages of decomposition at a similar rate (Table 17). Based on diver observations, within 6 days of submersion, all three pig carcasses were floating with the dorsal aspect towards the surface due to the manner in which the pig carcasses were secured to the bottom surface. No scavenging was visible. Between 5-11 days, all three pig carcasses had pulled free of their attachments and had to be re-secured to the bottom surface. After 32 days of

submersion, the soft tissue on Pig 2A appeared shredded, Pig 2B was bloated, but still intact, and Pig 2C was missing the majority of its abdominal cavity and appeared to be scavenged. After 52 days of submersion, the internal organs of Pig 2A were gone and the carcass was no longer floating. It was mainly some soft tissue, but the majority was skeletonized. The spinal column of Pig 2B was visible, but the carcass still maintained some buoyancy. Pig 2C had the least amount of decomposition, although the facial organs were missing. On the final day of data collection, after 81 days of submersion, each pig carcass was skeletonized and disarticulated, although Pig 2B still had some soft tissue present around the thorax.

Table 16 : Stages of decomposition adapted from Barrios and Wolff (2011)

Stage	Time Interval	Description
Submerged fresh	1-5 days	Intact, rigor mortis present, not floating
Early floating	6-17 days	Lividity present in abdominal region, discoloration present, abdominal bloating, and carcass floating
Floating decay	18-40 days	Discoloration of hind limbs, abdominal cavity ruptures
Bloated deterioration	41-48 days	Rupture of soft tissue as gas is released, carcass still floating, although the majority of the soft tissue has collapsed on itself
Floating remains	49-60 days	Only abdominal parts of carcass floating
Sunken remains	61-74 days	Complete skeletonization

Table 17 : Data collection date in which each pig progressed was observed at the decomposition stage based on diver observation and photographs.

Decomposition stage	2A	Submersion Interval*	2B	Submersion Interval*	2C	Submersion Interval*
Submerged Fresh	01/27/2012	0 days	01/27/2012	0 days	01/27/2012	0 days
Early floating	02/02/2012	1-6 days	02/02/2012	1-6 days	02/02/2012	1-6 days
Floating decay	02/28/2012	21-32 days	02/28/2012	21-32 days	02/28/2012	21-32 days
Bloating deterioration	03/06/2012	33-39 days	03/06/2012	33-39 days	03/06/2012	33-39 days
Floating remains	03/19/2012	40-52 days	03/19/2012	40-52 days	03/19/2012	40-52 days
Sunken remains	04/17/2012	67-81 days	04/17/2012	67-81 days	04/17/2012	67-81 days

* Submersion interval provided based on data collection dates since time restraints prevented daily observation.

Discussion

The results of this research indicate several important considerations for the application of side-scan sonar to detect submerged remains including: size of the body, terrain of the waterway, time limitations, swath width size, and frequency of the towfish. In Phase 1, the best parameters for conducting a forensic water search were investigated. Two variables that significantly influenced the success of the searches in Phase 1 were the swath width of the towfish and the location of the pig carcass. Atherton (2011) suggests a swath width that accounts for the smallest dimension of the body. Therefore, when searching for an adult body, the swath width should be no more than 25 m. In this project, 10 m and 20 m swath widths were compared, both under the maximum suggested swath width recommended by Atherton (2011). The first variable, swath width, affected the ability of the search team to maintain a transect within range of the pig carcass. The pig carcass was more likely to be outside the range of the sonar with the 10 m swath width than the 20 m swath width. Therefore, when searching for a submerged body, the 20 m swath width should be employed. The 20 m swath width provides the best compromise between distance and discernibility.

The location of the pig carcass also influenced the detection of the pig carcass. Vegetation inhibited detection, while a sandy, flat terrain facilitated it. If remains are located in close proximity to vegetation, side-scan sonar will not be able to discern the remains from the surrounding vegetation; therefore, another search technique should be employed. However, if the remains are located in a clear area or on a sandy bottom, the contrast of the remains with the surrounding terrain will facilitate detection of the remains.

In Phase 2, the effects of decomposition on the discernibility of the pig carcasses and the effects of size on the detection of submerged bodies were studied. Bodies decompose at a slower

rate in water than on land, and bodies in freshwater decompose faster than those in saltwater (Rodriguez, 1997; Petrik et al., 2004). While water environments typically inhibit insect activity (Petrik et al., 2004), a variety of scavengers have been observed feeding on submerged bodies, including crustaceans, fish, and turtles (Petrik et al., 2004; Barrios and Wolff, 2011). In Phase 2, scavenging was likely present, but could not be confirmed. Throughout the data collection period, the pig carcasses of Phase 2 were visible. However, as decomposition proceeded, the morphology of the pig carcass on the sonar image would change based on decomposition and disarticulation. For example, the carcass began as a feature on the bottom surface, progressed to a floating feature with a distinct pig-shaped shadow, then the floating feature and shadow no longer maintained the morphology of a pig, and finally, the image appeared as a tight cluster of features with little to no shadow around the central location. Even when the pig carcass was skeletonized and partially disarticulated, it could be discerned on the sonar image, albeit poorly. Therefore, submerged remains approximately the size of a human adult can be detected throughout the decomposition process as long as the operator can recognize the various manifestations of the decomposing remains on the sonar images.

Additionally, the size of the remains will affect the decomposition state, and consequently the sonar image. Larger bodies will create more reflection area and retain their distinct morphology longer. Hence the larger the body, the easier it will be to discern on the sonar image. When comparing the small carcasses from Phase 1 to the medium carcasses from Phase 2 the effects of size can be analyzed (Figure 33). After 11 days submerged, Pig 1A was visible, but neither the feature nor the shadow was distinct. However, Pig 2A was distinctly a pig carcass and the shadow had the same morphology of a pig after 11 days submerged. After 18 days submerged in Phase 1, the pig carcass feature was barely visible, but the shadow was still

distinct. For Phase 2, after 20 days submerged the pig carcass feature was still visible, and the shadow was distinct. Also, scavenging will affect decomposition state, and must be considered. Divers noted scavengers such as soft-shell turtle (species not noted) and small fish. Moreover, an otter was observed in the borrow pond, and alligators inhabit most freshwater waterways in Florida, although none were observed during data collection. In Phase 2, all three pig carcasses were in a similar environment, yet the decomposition of each pig carcass was concentrated in different regions. Since decomposition affects the manifestation of the feature and shadows on the sonar image, a thorough understanding of the size of the target, as well as the time interval for submersion and the scavengers present will aid searchers in identifying the remains.

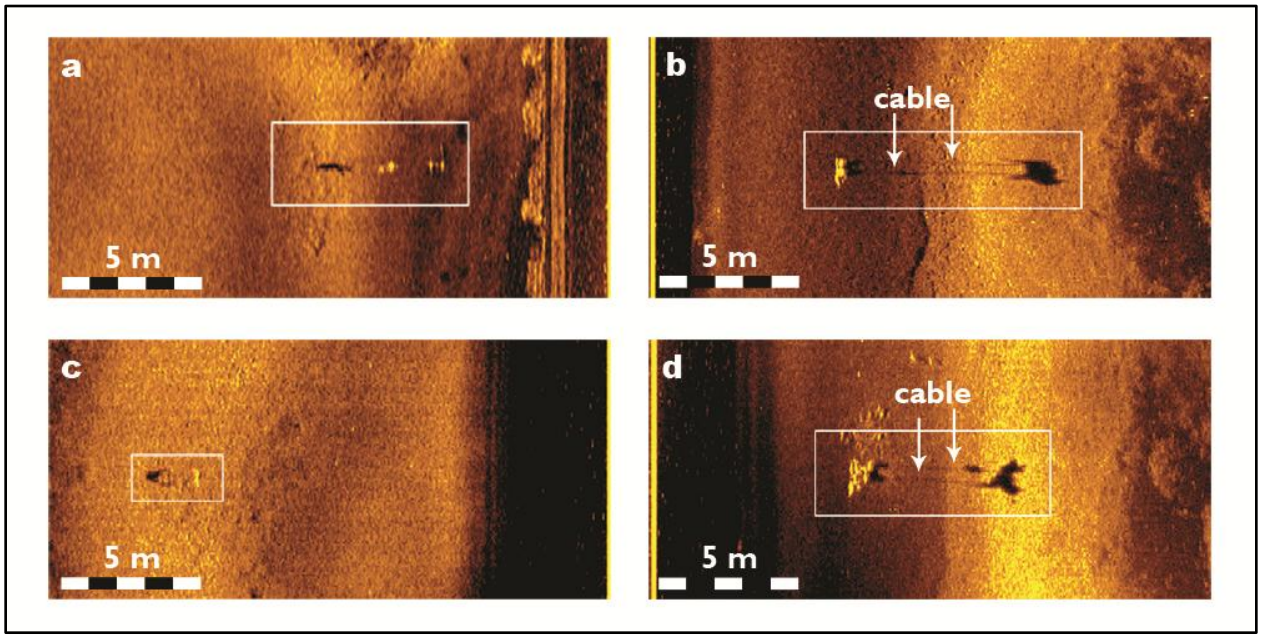

Figure 33: Comparison of sonar images for each phase by submersion time; all images are 1800 kHz, 20 m swath width: a) Phase 1, 11 days submerged; b) Phase 2, 11 days submerged; c) Phase 1, 18 days submerged; d) Phase 2, 20 days submerged.

Another variable that should be considered when conducting a forensic water search is the frequency of the towfish. Lower frequencies have less resolution. Atherton (2011) recommends a frequency of at least 400 kHz for submerged body searches, and the frequencies

utilized in this project were significantly larger than those suggested by Atherton. However, for this research project, there was only a slight difference between the visibility of the pig carcass with the 900 kHz frequency and the 1800 kHz frequency. In Phase 1, with smaller carcasses, the remains were more visible with the 1800 kHz frequency, but in Phase 2, with larger carcasses, the 900 kHz frequency provided better images of the remains. Moreover, in Phase 2, the 900 kHz frequency scored "excellent" 7 times, while the 1800 kHz frequency only scored "excellent" 4 times. Therefore, the 900 kHz frequency would be a better option for searches for the submerged bodies of medium sized carcasses, but the 1800 kHz frequency would be a better option when searching for small carcasses.

Moreover, when comparing the image quality between Phase 1 to Phase 2, the images for Phase 2 were noticeably better, as reflected by the scores for each phase. The difference between Phase 1 and Phase 2 can be attributed to two variables. One, over time, the personnel involved in this research project became more experienced in the operation of the sonar as well as navigating the boat. Two, the pig carcasses in Phase 2 were larger, provided a larger feature for the sonar to locate. Both of these variables increased the success of Phase 2, and these variables must be understood when beginning a search. Operator experience, driver experience, and size of the body all significantly affect the success of a search.

Conclusion

When utilizing side-scan sonar for a search for a submerged body in shallow, freshwater lakes or ponds in humid, subtropical environments, several variables must be considered. First, the terrain of the lake must be investigated before beginning a search to determine if sonar could be applicable to the lake. If the possible location of the body is in vegetation, other search techniques should be investigated. However, if the lake bottom is clear, sonar could be a useful

search option. Depth fluctuations can also affect the success of a search, although an experienced sonar operator can often counteract this challenge.

The experience of the sonar operator and boat driver can significantly affect the success of the search as well. The difference between Phase 1 and Phase 2 illustrate the learning curve of both the sonar operator and the boat driver. Even though the OCSO Marine Unit had significant training prior to Phase 1, all members benefited from the consistent use of the sonar unit. Moreover, the success of Phase 2 can be attributed to the experience obtained from Phase 1 of the research. Therefore, operators and drivers should train with the sonar unit at regular intervals to ensure their familiarity with the side-scan sonar prior to a search for a submerged body.

CHAPTER FOUR: OVERVIEW OF RESULTS AND GUIDELINES FOR BEST PRACTICES FOR THE USE OF SIDE-SCAN SONAR IN FORENSIC CONTEXTS

Introduction

Due to an increase in the incorporation of side-scan sonar into forensic water searches, standards must be established in order to increase the success rate for locating submerged bodies and evidence with this technology. Controlled research is an invaluable method for determining the variables influencing the effectiveness of side-scan sonar for forensic contexts as well as providing invaluable experience for those operating the sonar. Additionally, an understanding of the best parameters for forensic searches is necessary for efficient and successful searches. Controlled research provides a structured environment in which the best practices for the use of this technology can be established (Schultz et al., 2006; Schultz, 2007; Schultz and Dupras, 2008; Schultz, 2008). Additionally, controlled research provides experience for the operators as well as determines variables that will increase the success of a search. Since there is a lack of literature on controlled research employing side-scan sonar, it is paramount to investigate the advantages and disadvantages of this technique for forensic contexts prior to utilizing it for forensic searches.

Guidelines for Best Practices

The increased use of side-scan sonar in forensic contexts calls for standardized practices of use and a thorough discussion on when side-scan sonar can be effectively utilized. Figure 34 provides a flow chart of when to use side-scan sonar and the appropriate parameters to utilize.

When conducting a water search with side-scan sonar, the nature of the terrain should first be considered. A quick pass over the suspected area with the sonar can provide valuable information on the terrain and help determine the effectiveness of side-scan sonar, and preclude the use of sonar if vegetation is present. Moreover, fluctuating or sloping terrain can also create challenges for the sonar operator. Understanding the slope of the terrain allows the sonar operator to better search the area, and as the search proceeds, the sonar operator can predict the changes in elevation and adjust the depth in advance.

Once the necessary parameters are established for the sonar search, a search area should be established. While the sonar unit has the capabilities of denoting a search area, OCSO Marine Unit has found that the search area within the sonar unit is not as reliable, and it is more difficult for the boat driver to align transects off of the sonar unit. Instead, buoys can be employed at the corners of the search area. This allows the boat driver to align each transect off of the buoys and ensure that the entire search area is covered. The sonar operator should use the sonar unit's plotter to provide another method to ensure the entire search area is covered. Each transect should overlap approximately 50% of the previous transect (Atherton, 2011). By providing overlap, a suspected target will be visible at least twice. This provides multiple views of the target. Additionally, after a target is discerned, a buoy should be deployed over the target to mark the suspected location and divers should further investigate the target (Winskog, 2011).

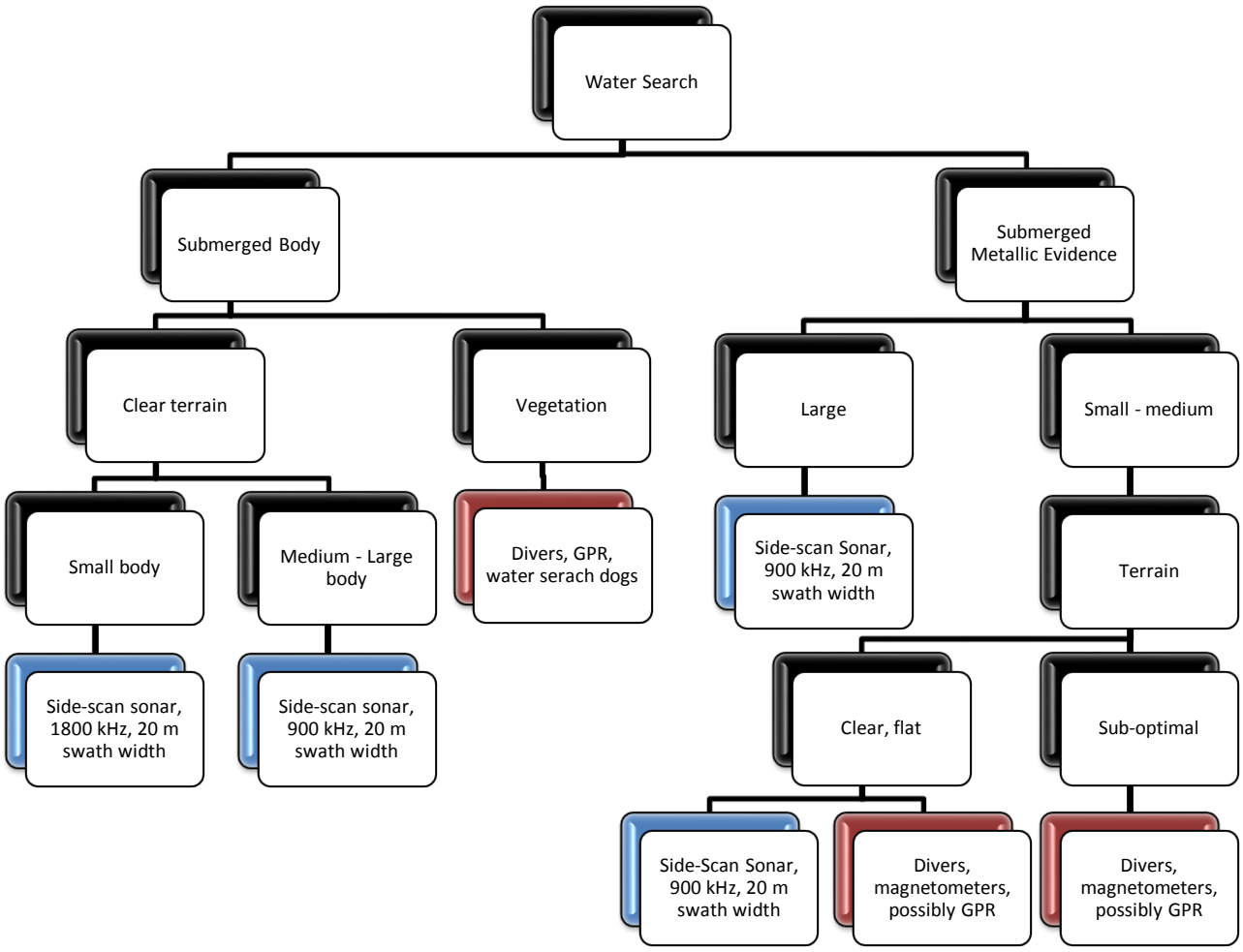

Figure 34: Flow-chart for the use of side-scan sonar for submerged body searches and submerged evidence searches

Swath Width Comparison

For initial searches, the most efficient swath width should be employed to minimize time, and yet ensure that the target is still discernible. This research focused on the appropriate swath width for searches for small to medium cadavers, using pig carcasses as proxy cadavers. Since the swath width can affect the size of the feature on the monitor, the size of the feature must be considered when determining the appropriate width. Smaller features should utilize a smaller swath width, while larger features can employ a larger swath width. Additionally, the size of the

search area should be a variable when determining the swath width. Larger swath widths minimized the number of transects needed, which also minimizes the time required to search. Therefore, when there are time considerations, the largest swath width that can detect the target should be employed.

Of the two swath widths investigated, the 20 m width was most appropriate for searches for submerged bodies in freshwater lakes and ponds in a humid, subtropical environment in Central Florida. Although the feature appears small on the monitor, the 20 m width can detect submerged remains, including bodies as small as a child, while minimizing the number of transects necessary to search for the remains and still maintaining the suggested 50% overlap (Atherton, 2011). For this research, even experienced drivers had difficulties navigating the sonar within 10 m of the target, as the majority of transects that were out of range were of the 10 m swath width. A 50% overlap of each transect would be extremely challenging to navigate due to the size of the boat as well as the environmental conditions present, such as wind. Hence, a 20 m swath width should be utilized when searching for submerged bodies.

Frequency Comparison

Of the two frequencies, the 900 kHz frequency was marginally better at detecting submerged remains than the 1800 kHz frequency for larger carcasses. For smaller bodies, the 1800 kHz frequency was able to discern the remains more often. In general, both frequencies were able to detect submerged remains, but the 900 kHz frequency provided a more distinctive image than the 1800 kHz frequency. However, employing both frequencies will assist in identifying a target, as each frequency provided a different image. For a search for a submerged adult body, the 900 kHz frequency should be utilized, but the 1800 kHz frequency can provide better resolution when differentiating between two possible features. Therefore, initial searches

should be conducted utilizing the 900 kHz frequency, but when possible targets are located, the 1800 kHz frequency should be employed to further investigate the target if a more detailed image of the anomaly is needed prior to deploying divers.

Conclusions

Side-scan sonar is a viable tool for forensic water searches. While additional research is necessary to determine the applicability of this technology to forensic evidence searches, side-scan sonar has proven to be an excellent tool for detecting submerged bodies in a humid, subtropical environment. Although the vegetation and terrain of the waterway must be considered prior to searching, if the necessary conditions are satisfied, side-scan sonar can reduce the manpower required to search for a submerged body, locate the body faster, and identify the body despite inclement conditions. Utilizing the 900 kHz frequency and a 20 m swath width will be the most efficient and effective parameters to search for a submerged body.

Additionally, the experience of the sonar operator and boat driver can affect the success of a search. Therefore, periodic training with the equipment is necessary to ensure each person has enough experience to not only conduct a search, but locate a submerged body. As this research has illustrated, the morphology of bodies can change based on a number of variables, and therefore, an understanding of the basic features will help the operator identify a submerged body. Moreover, operators must be able to distinguish between normal features of a lake, such as fish or alligators, and the target. Experience provides the operator the necessary skills to differentiate between targets and other features of the lake.

A thorough understanding of the advantages and disadvantages of side-scan sonar, as well as the conditions necessary to conduct a successful search are paramount to an efficient and effective side-scan sonar search. This research has established the best practices for locating a

submerged body in shallow freshwater lakes and ponds in a humid, subtropical environment in Central Florida. Additional research in other environments will provide valuable information on other variables that affect sonar searches. Moreover, additional research in a variety of settings will aid in the understanding of the applicability of side-scan sonar to forensic evidence searches. Finally, a comparison of side-scan sonar with other geophysical methods could provide a reference to assist law enforcement agencies on choosing the appropriate geophysical tool when conducting a forensic water search.

Side-scan sonar is a practical technology to utilize for forensic water searches, and as more law enforcement agencies purchase this technology, a thorough understanding of sonar and the variables that affect the success of a sonar search are necessary. This research has established best practices for the use of side-scan sonar in shallow lakes and ponds in humid, subtropical environments in Central Florida, which will aid law enforcement agencies in the area when conducting forensic searches.

APPENDIX A: SPECIAL USE AUTHORIZATION

SPECIAL USE AUTHORIZATION

This Special Use Authorization ("Authorization") is given by St. Johns River Water Management District ("District") to University of Central Florida ("User"), 4000 Central Florida Boulevard, Phillips Hall 309, Orlando, Florida 32816, whose contact is John J. Schultz, Ph. D., john.schultz@ucf.edu and User's employees and agents.

The special use authorized is a controlled research project detecting submerged remains utilizing side-scan sonar to detect proxy cadavers at Hal Scott Regional Preserve and Park (the "Project"). Attached as Exhibit "A" is a description of the project. The three maps attached as Exhibit "B" show the location of the use, access points and routes.

The Use is authorized for a non-renewable period of 7 months, beginning August 17, 2011, and expiring May 31, 2012 , (timetable attached) and is subject to the following terms and conditions:

1. User must coordinate all aspects of its activities with the District's Land Manager for the Hal Scott Regional Preserve and Park, Peter Henn, 407-977-6290 or phenn@sjrwmd.com.
2. User can access anywhere at the borrow pit/pond site on the map (Exhibit "B", page 2) but will not submerge any pigs in the red crosshatched area on the map (Exhibit "B", page 2).
3. User acknowledges that separate special use authorizations may be given by the District to others for use of the Property during the same time period prescribed by this Authorization. User may use the Property to the extent required for the Use and shall not prevent any other authorized users from carrying on their approved activities.
4. User will not cause damage to the Property beyond that normally associated with the activities authorized during the dates listed above.
5. User will clean and restore the Property at the conclusion of the use to not less than the condition that existed prior to the use. User will repair any damage to the Property resulting from the use during the dates listed above. All expenses for the repair shall be borne by User.
6. User's vehicular access shall be limited to the area depicted on Exhibit "A."
7. User must close and lock gates at the time of each entry and exit to and from the Property to ensure that unauthorized persons are not enabled access to the Property.
8. User's use of the Property shall in no way impede the access of others.
9. User shall notify the District of any third party contractor(s) that will be accessing the Property under the terms of this Authorization. Any such contractor(s) shall at all times during the term of this Authorization, be required to maintain a policy of general liability insurance covering personal injury and property damage in an amount acceptable to the District's Executive Director. A certificate of insurance naming the District as an additional insured under the policies shall be presented prior to access by said contractor(s).

10. User/contractor(s) at all times during the term of this Authorization shall maintain automobile liability insurance with appropriate limits of coverage acceptable to the District's Executive Director and shall be required to produce evidence of such insurance upon request.

11. The District shall bear no financial cost, expense or obligation to the User as a result of this Authorization.

12. All personal property placed upon, or moved in or upon the Property by User shall be at the sole risk of the User.

13. User shall exercise due care against accidentally starting fires while on the Property. User shall be held liable for all damages caused by such fires.

14. The Discharge of any fuel, oils, petroleum products, litter or other harmful materials that may result from User's use of District land is prohibited. Should any harmful materials be discharged on the land by User during the term of this Authorization, the District shall be immediately notified, and the User shall be solely responsible for any and all costs associated with any resulting clean up and remediation.

15. Killing, molesting, or trapping of any wildlife is prohibited.

16. Except, as otherwise authorized herein, the harvest of any plant or plant material is prohibited.

17. User shall be solely responsible for obtaining any other permits or authorizations as may be required for User to utilize any portion of property other than that portion owned by the District.

18. User shall abide by all applicable governmental rules, regulations, ordinances and laws with respect to User's use of the Property.

19. User is under a duty to be vigilant for User's own safety as well as the safety of others. User understands and agrees that User is responsible for User's personal safety and the personal safety of any and all persons accompanying User on the Property or accessing the Property under the direction of User. User is fully knowledgeable of the risks that are generally associated with traversing Property that is in a substantially natural condition and assumes all such risks. User also assumes all risks associated with traversing District lands in a motor vehicle and takes the condition of the Property "as is." User voluntarily assumes any other risks, of every kind whatsoever, whether natural or artificial, while conducting activities on the Property pursuant to this Authorization.

20. User agrees that nothing under the terms of this Authorization or any use contemplated under this Authorization shall render the District liable for property or personal damages resulting from the use. The User, its successors, assigns, heirs, executors, and administrators, do hereby agree to indemnify and hold the District harmless from any and all liability for bodily or personal injuries, claims of negligence, property damage or loss, and all other causes of action in law whatsoever attributable to activities of User or any of its

Only to the extent specifically required by Florida law, including Fla. Stat. §768.28,

YPC 8-16-11 WA. 8-24

participants, including the District's costs and attorney's fees. User understands that this waiver includes any claims based on partial or sole negligence, action or inaction of User, its employees, representatives, successors and assigns. Each party agrees to be responsible for its own negligence and that of its employees, servants, and agents!

21. Except as otherwise authorized herein, User will comply with of the District's Water Management Lands Acquisition and Management Rule, Chapter 40C-9, Florida Administrative Code a copy of which may be viewed at: www.floridaswater.com/rules/pdfs/40C-9.pdf.
22. This Authorization is revocable at will.
23. Nothing contained in this Authorization shall be construed as a waiver of or contract with respect to the regulatory and permitting authority of the District as it now or hereafter exists under applicable laws, rules and regulations.
24. User must physically have a copy of this Special Use Authorization at all times while on the Property.
25. This Special Use Authorization does not convey any real Property interests or rights to User of any kind. The authorization granted hereby shall neither be transferred nor assigned. User is solely responsible for obtaining any permits or other forms of authorization required by law from federal, state or local governmental entities in order to engage in the activities that are the subject of this Authorization.

UNIVERSITY OF CENTRAL FLORIDA

I agree to the conditions above and warrant that I am authorized to sign on behalf of the User.

By: _____

Print Name: Michael D. Johnson

Title: Interim Dean, College of Sciences

Date: 8/17/2011

ST. JOHNS RIVER WATER MANAGEMENT DISTRICT

Authorization based on conditions above is approved.

By: _____
Steven R. Miller, Director
Division of Land Management

Date: 8/29/11

Approved as to form

By: _____
Office of General Counsel, SJRWMD.

Legal Content Approved
VCC 8/16/11
Subject to change(s) noted

APPROVED
_____ 8-19-11
TONY G. WALDROP DATE
PROVOST AND EXECUTIVE VICE PRESIDENT

Exhibit "A"

Detecting Submerged Remains: Controlled Research Using Side-Scan Sonar to Detect Proxy Cadavers

John J. Schultz, Ph.D.
(Member, Physical Anthropology Section)
4000 Central Florida Blvd.
Phillips Hall, 309
Department of Anthropology
University of Central Florida
Orlando, FL 32816

Category: FSF Lucas Grant

June 15, 2011

DESCRIPTION OF PROJECT

Geophysical technologies are frequently employed by death investigation personnel for searches involving clandestine bodies and forensic evidence. In forensic contexts, geophysical methods are used not only to locate forensic targets, but to eliminate suspected areas so that search efforts can be focused elsewhere. A main advantage of using geophysical technologies for forensic applications on land includes remote sensing techniques that are non-invasive which results in preservation of the context of the site (Davenport, 2001; Dupras et al., 2006; Schultz and Dupras, 2008). In other words, these tools are used to survey an area without damaging the ground surface or buried evidence. Once suspicious areas are located in a much larger search area, minimal effort can then be used as a follow-up to only search the smaller suspicious areas that were identified during the larger geophysical search. Furthermore, geophysical technologies can also be used to detect human remains and forensic evidence that are submersed underwater.

Side-scan sonar is regularly used to locate specific targets such as shipwrecks or downed airplanes (Quinn et al., 2002; Church et al., 2002; Garret, 2006; Dumser and Türkay, 2008). In recent years, side-scan sonar has become a valuable technology used to detect human remains in water environments. While side-scan sonar is used to detect bodies in water as a result of airplane crashes, helicopter crashes and boating accidents, a number of cases have employed side-scan sonar to search for missing persons and murder victims that were suspected to have been dumped in a water environment. For example, law enforcement agencies and volunteer search and recovery groups have utilized side-scan sonar in high-profile searches, such as the Laci Peterson, Natalee Holloway, and Brian Reed cases (Garret, 2006; WFTV.com, 2004).

Side-scan sonar uses sound to detect features or anomalies on the floor of bodies of water by pulling a towfish, containing the transducer, which is connected to a boat by a cable (Dupras

et al., 2006). The transducer emits repeated pulses into the water and then receives the returning echoes. The time for the echo to return and the strength of the echo is used to calculate and discern features on the sea floor. The received pulse is converted into a digitized signal which is transmitted up the cable to the monitor on the boat. The sonar operator can follow the data collection in real-time on the monitor to discern features. Side-scan sonar is becoming a preferred remote sensing for water environments because the image produced by this equipment is akin to an aerial image, as the image provides a picture of the lakebed or seafloor. This technology produces the best resolution out of all the geophysical technologies used for body and evidence searches (Dupras et al., 2006).

Side-scan sonar is increasingly being used for body searches by replacing divers on the initial search. Once features and or suspicious areas are located, divers can be employed to search limited areas highlighted by the side-scan sonar search. In addition, side-scan sonar can be used to search significantly larger areas that are too large for divers, thus locating bodies earlier in the decomposition process and decreasing the time and manpower needed to search. Many law enforcement agencies must perform body searches in areas of low visibility where the divers can only feel along the lake bed rather than visually identify targets. Since side-scan sonar is not affected by the visibility of water, this equipment provides a major advantage compared to only using divers that are limited by visibility. Additionally, the equipment can reduce the risk to divers in extreme conditions such as strong currents, low visibility, and debris-littered areas. However, to date, controlled research has not been conducted to determine search protocols, limitations, and best practices for the use of side-scan sonar. Furthermore, while the use of side-scan sonar has been increasingly employed for forensic applications, there has been

no publications discussing the application of this technology in either *Journal of Forensic Sciences* or *Forensic Science International*.

As more law enforcement agencies are using side-scan sonar for body searches, there is an increased need to establish the best practices for its use, including an understanding of the use of this technology for different areas of the country concerning evidence and body searches, as well as the limitations and factors that may affect the success of the survey. Controlled research is devised to limit the number of variables (i.e., carcass size, postmortem interval, environment, etc.) in order to better understand how these variables affect real-life searches (France et al., 1992; France et al., 1997; Schultz et al., 2006; Schultz, 2008). In addition, since the success of the survey is significantly affected by the experience of the operator, controlled research allows operators to gain experience in a known environment. Controlled research in the areas of taphonomy and geophysical methods often use pig carcasses (*Sus scrofa*) as proxies for human cadavers (France et al., 1992; France et al., 1997; Schultz et al., 2006; Schultz, 2008). Also, entomology research (Catts and Goff, 1992; Goff, 1993) has shown that pig carcasses are the most appropriate animal proxy for the study of human decomposition and are fairly easy to procure.

Research Objectives and Benefits

Currently, many law enforcement agencies primarily use divers to search for bodies and evidence underwater. However, the use of divers requires significant man-power and time, and murky water can significantly limit the effectiveness of the divers. Since a side-scan sonar survey can cover large search areas in less time than numerous divers performing a grid search, side-scan sonar can reduce the man-power and time to search for remains, while maintaining the context and diminishing the taphonomic forces at the scene. Additionally, side-scan sonar is not

affected by the visibility of the water or conditions, which makes this technology an effective tool to use in conjunction with other search methods such as divers. Once a suspicious area is located during a side-scan sonar search, divers can inspect the much smaller suspicious area.

The objective of this research is to establish protocols and best practices for the detection of submerged human remains using side-scan sonar. Overall, the proposed project will be part of a larger more comprehensive project also testing submerged evidence such as large weapons and other items associated with a submerged body. Finally, another goal of this project is the development of a library of side-scan sonar images of known items, including bodies at different stages of decay, to assist death investigators in the interpretation of side-scan sonar imagery.

Research Protocol

This research will be possible due to a partnership with the Orange County Sheriff's Office (OCSO) Orlando, FL, Marine Unit. The research protocol will involve three phases and a total of seven pig carcasses will be utilized. The OCSO Marine Unit has identified two possible lakes on private land in the central Florida area to perform the research. Before each of the pig carcasses is staked to the bottom, the location will be noted using GPS coordinates. An OCSO diver from the Marine Unit will then stake the carcass to the bottom of the lake and note the make-up of the lake bottom in that location (i.e. mud, silt, weeds, debris), as this can affect the reflectivity of the acoustic echoes. A grid survey of the lake area will then be performed using a Marine Sonic Technology, LTD side scan sonar system (Centurion model with a dual frequency 900/1800 kHz towfish). The target sample will represent two groups of three pigs that will be surveyed during two different seasons to determine the possible effect of seasonal temperature with detection over time. Data collection will be repeated approximately every two weeks, based

on availability of the Marine Unit, until the carcasses can no longer be detected. We will also plan to possibly conduct a blind trial if trained personnel are available.

Phase I - One pig carcass will be utilized to refine the search protocol and to determine how to stake the carcass to the lakebed so alligators do not remove the carcass. Since alligators are a natural scavenger that will feed on submerged bodies in this area of the United States, we need to secure and possibly cover the carcasses so they are not removed soon after they are placed on the lakebed. This phase will involve determining an appropriate method of securing the carcasses so we will be able to return a number of times to the lake for data collection. We hope to be able to collect longitudinal data during the Phase II and Phase III components to determine if we can detect the carcasses while they are decaying, and to determine at what point during decomposition we can no longer detect the carcasses with side-scan sonar.

Phase II-The first group of three pig carcasses will be staked to the lake bottom in different locations during late summer. Longitudinal data collection will be performed until the carcasses can no longer be detected or for a three month period.

Phase III-The second group of three pig carcasses will be staked to the lake bottom in different locations during the Florida winter months. Longitudinal data collection will be performed until the carcasses can no longer be detected or for a three month period. In addition, data will be compared between the two groups of carcasses.

Phase IV- Best practice guidelines for body searches will be compiled using results from this research project as well as casework experience by the OCSO Marine Unit.

Exhibit "B"

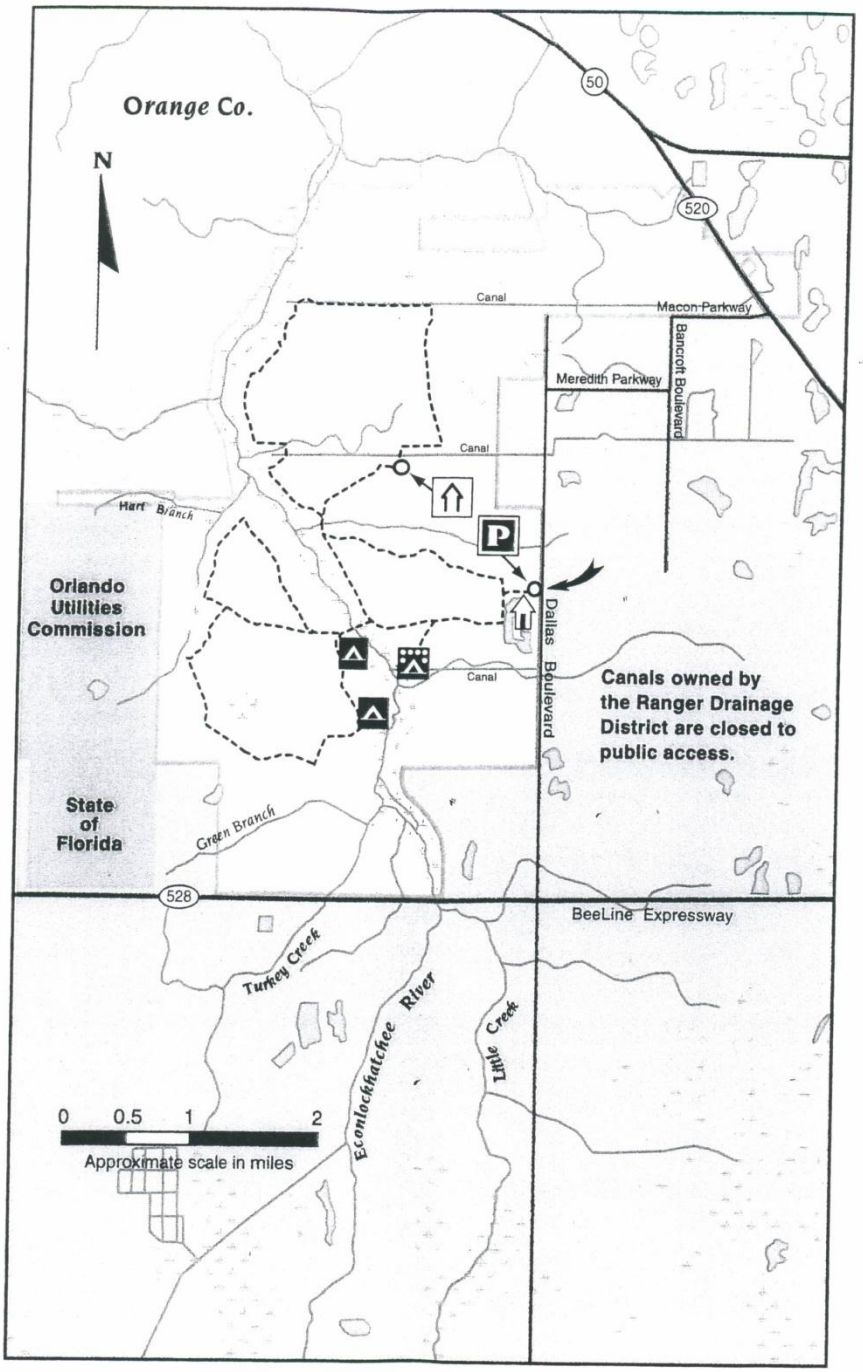
Orange Co.
N
50
520
Canal
Macon Parkway
Meredith Parkway
Bancroft Boulevard
Canal
Hart Branch
Orlando Utilities Commission
Dallas Boulevard
Canal
Canals owned by the Ranger Drainage District are closed to public access.
State of Florida
Green Branch
528
BeeLine Expressway
Turkey Creek
Econlockhatchee River
Little Creek
0 0.5 1 2
Approximate scale in miles

Exhibit "B"

APPENDIX B: SONAR IMAGES FROM PIG 1A

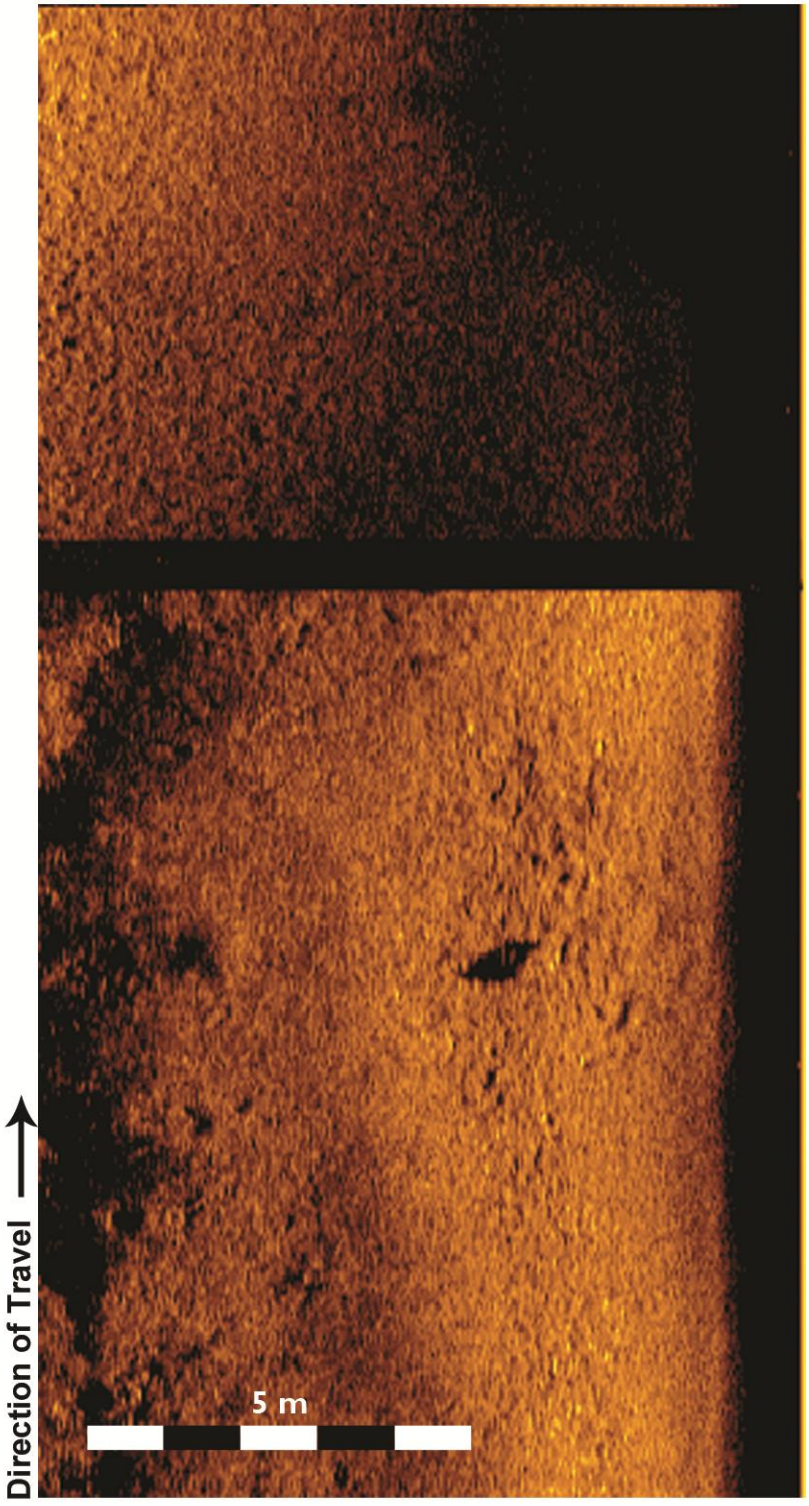

Figure 35: File 31Oct142, 1800 kHz, 10 m, acoustic signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

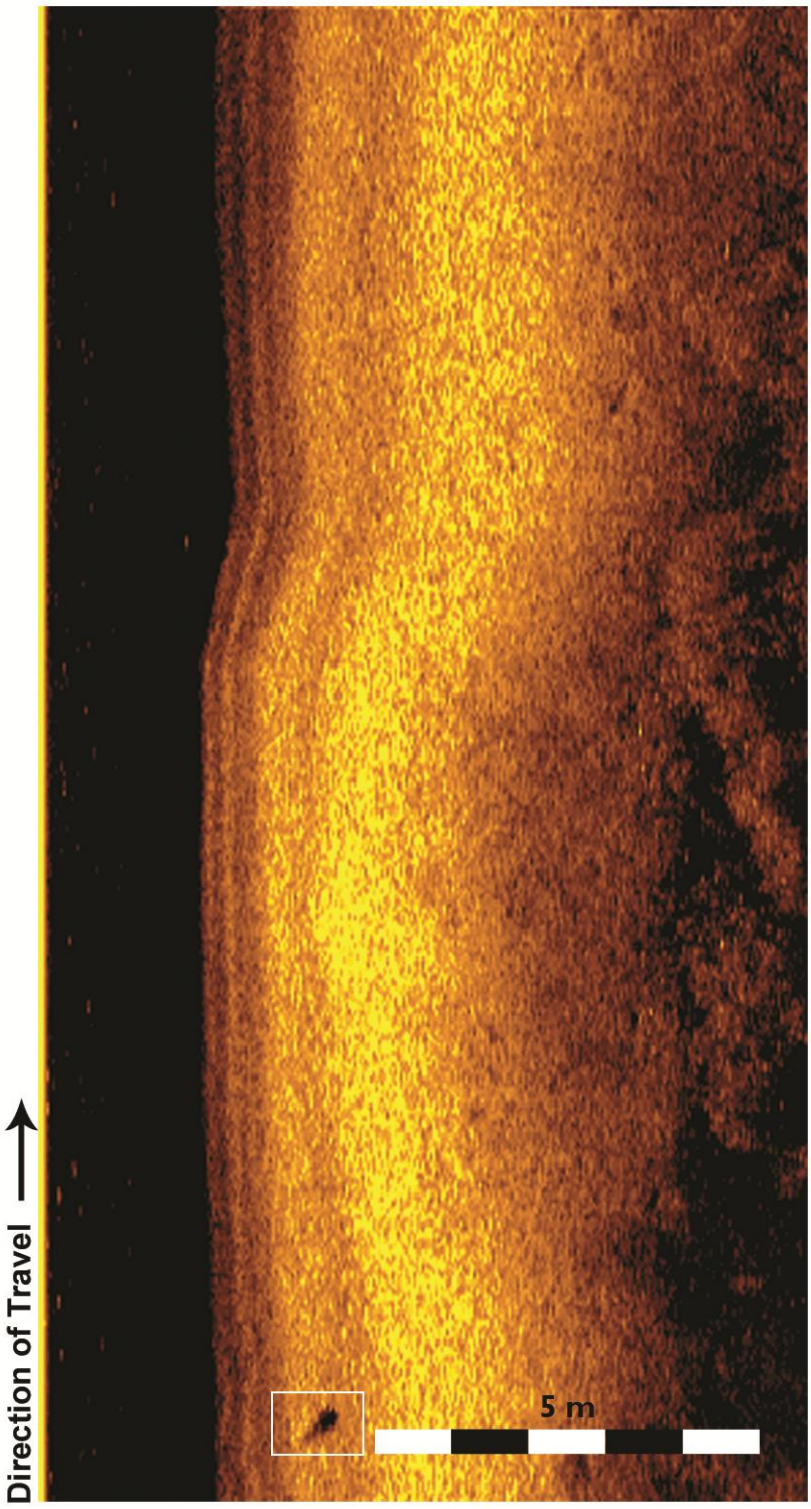

Figure 36: File 01Nov027, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass possibly detected and scored as "poor."

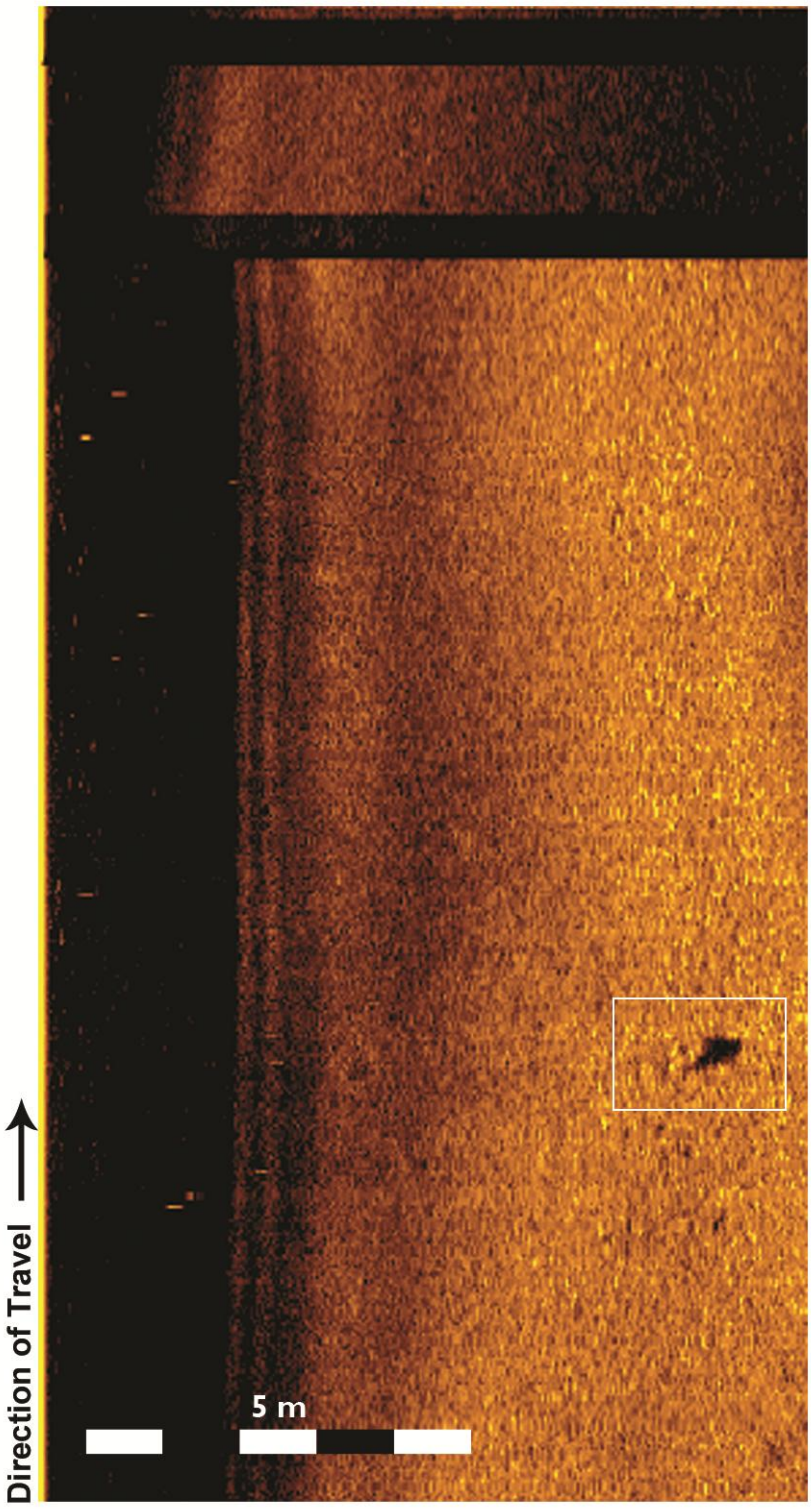

Figure 37: File 01Nov049, 1800 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "poor."

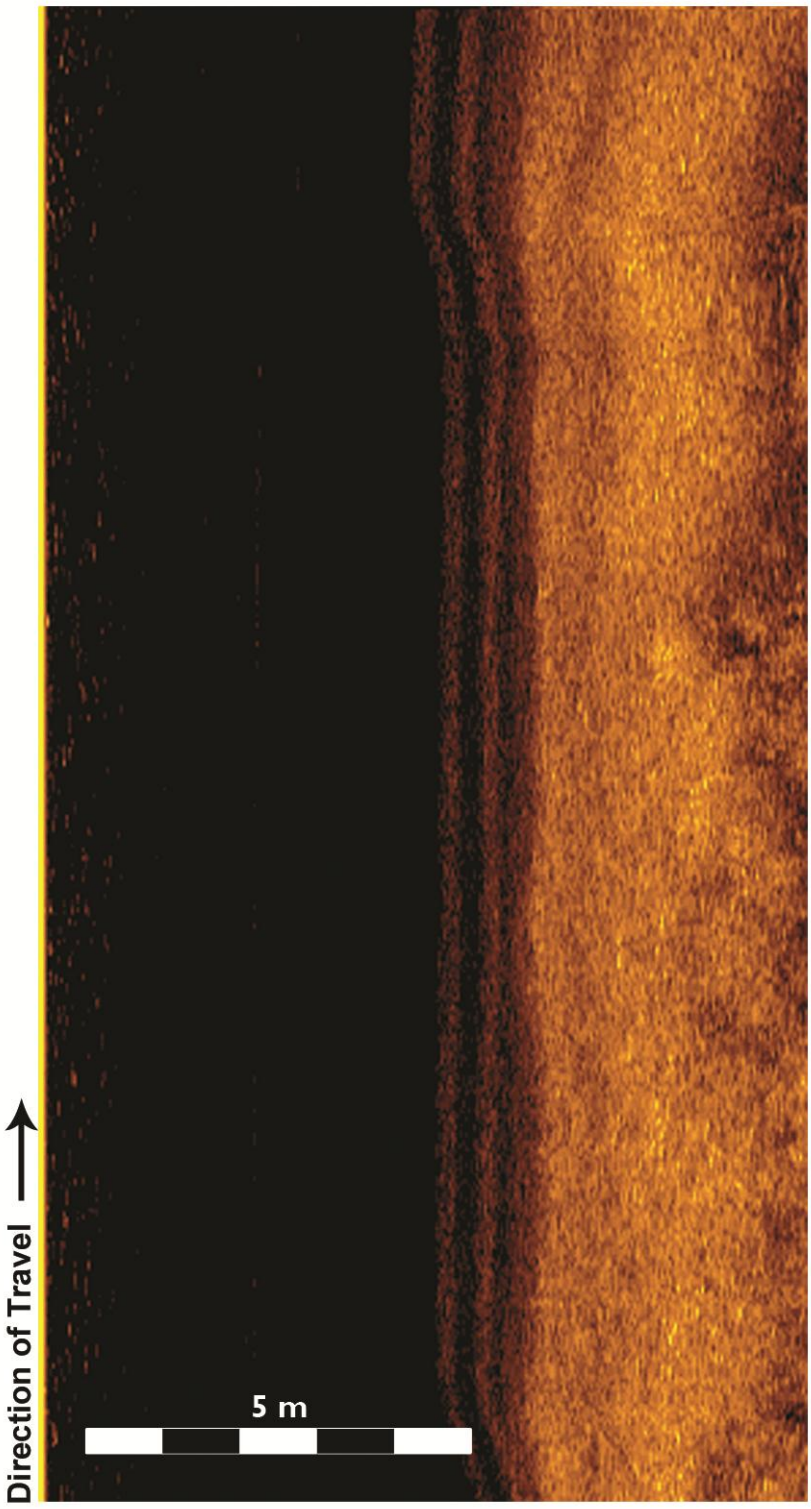

Figure 38: File 04Nov006, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

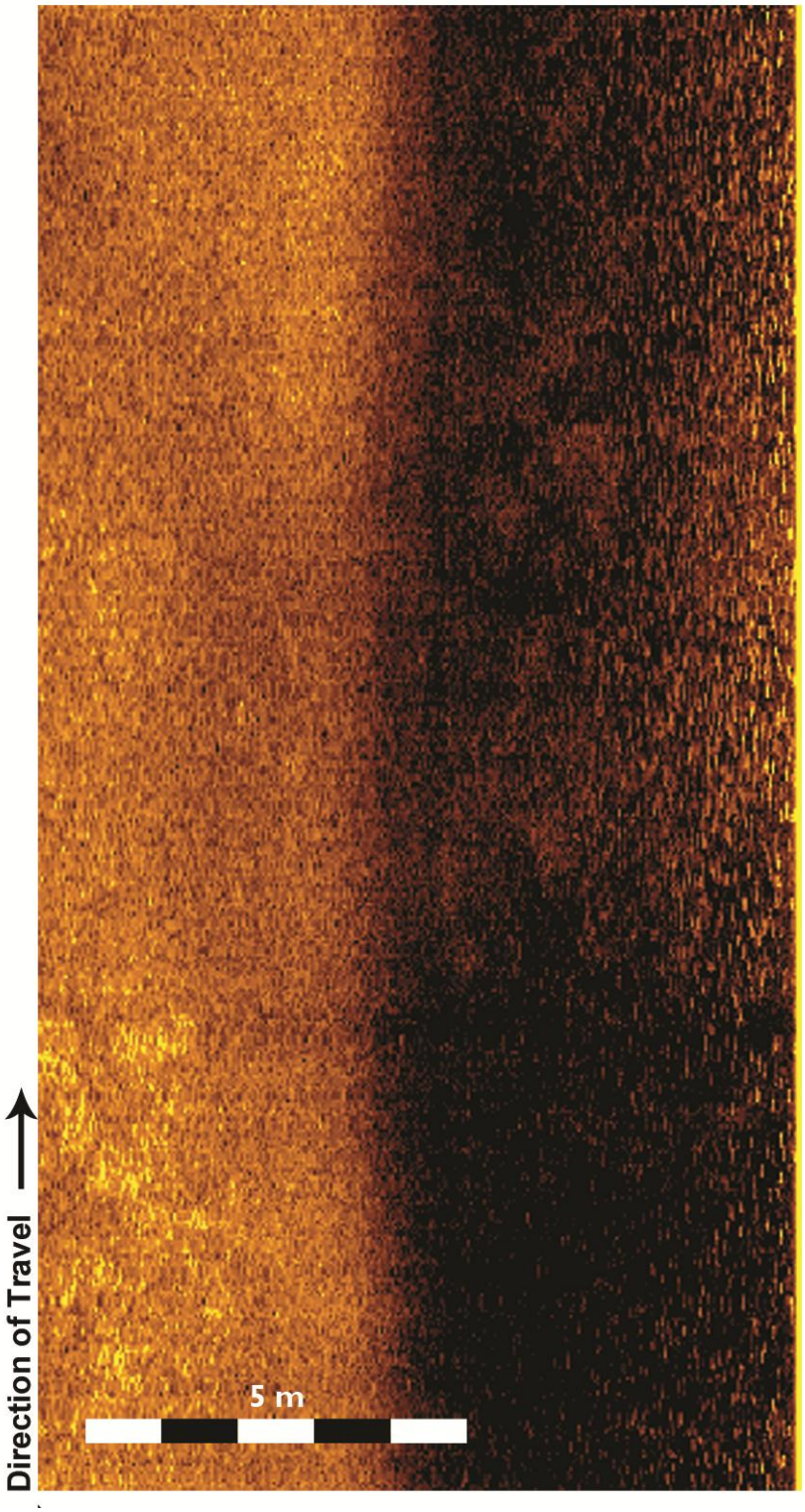

Figure 39: File 04Nov041, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

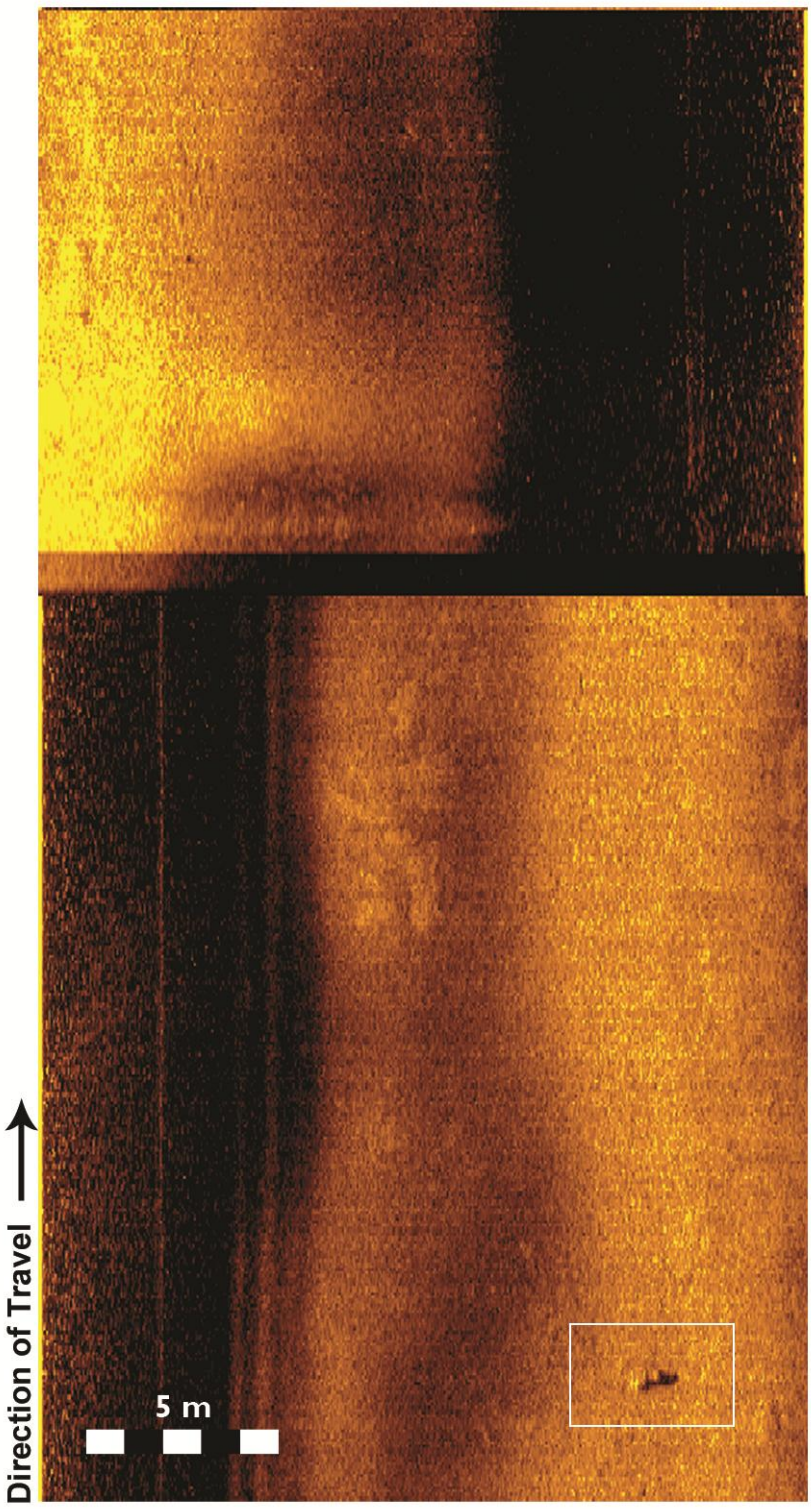

Figure 40: File 04Nov052, 1800 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "poor."

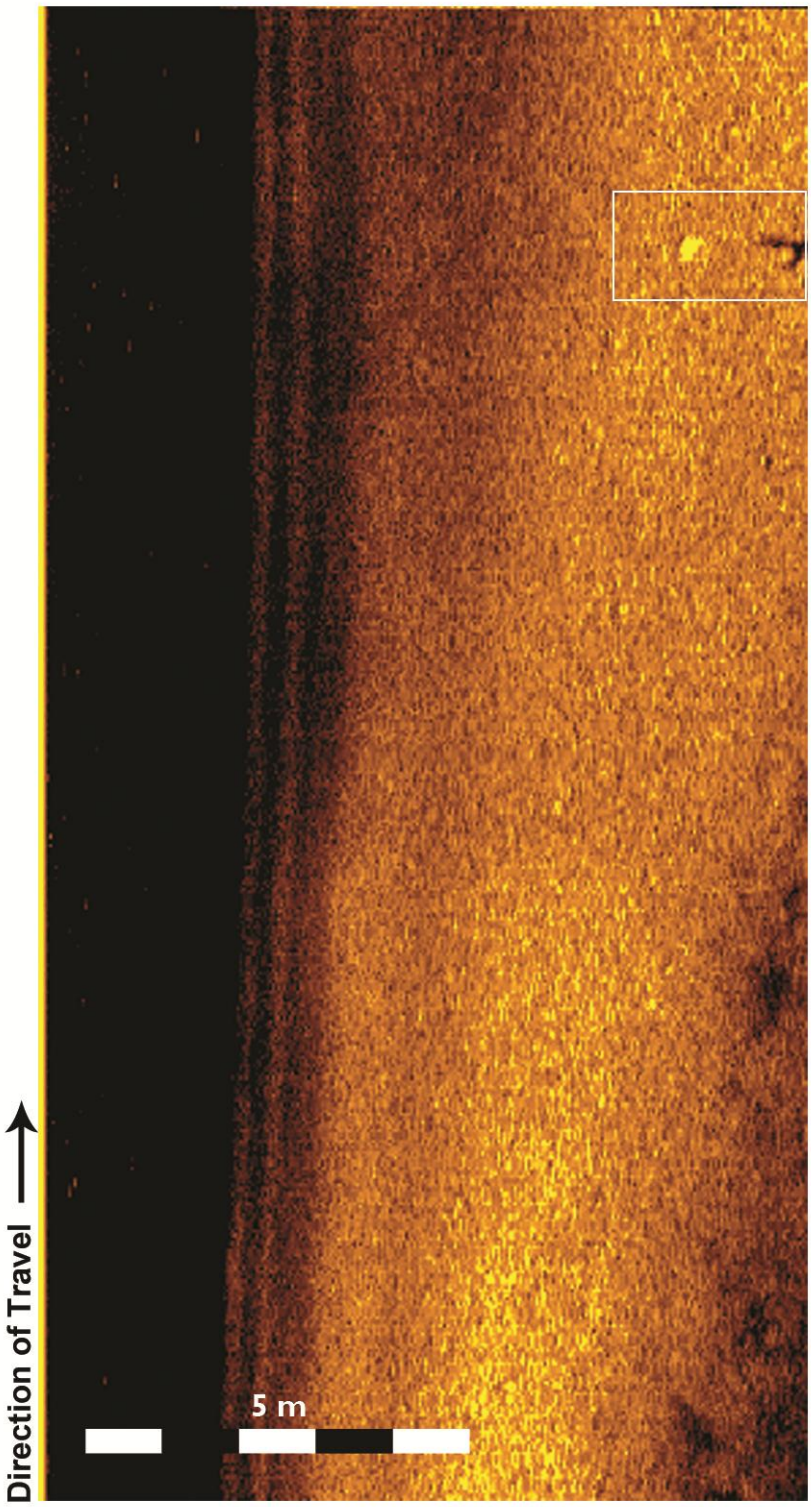

Figure 41: File 11Nov011, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "poor."

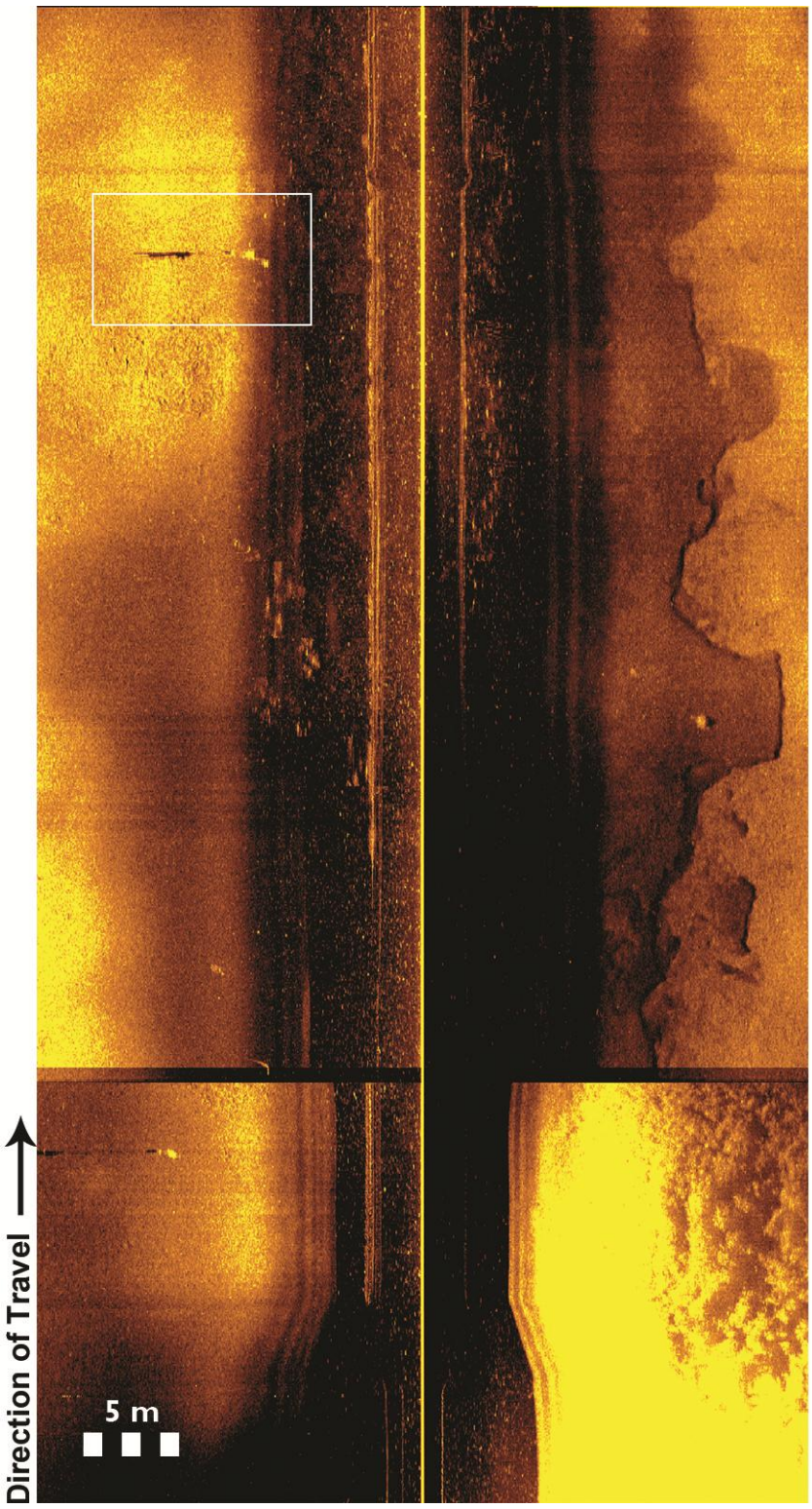

Figure 42: File 11Nov060, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [top] detected and scored as "good."

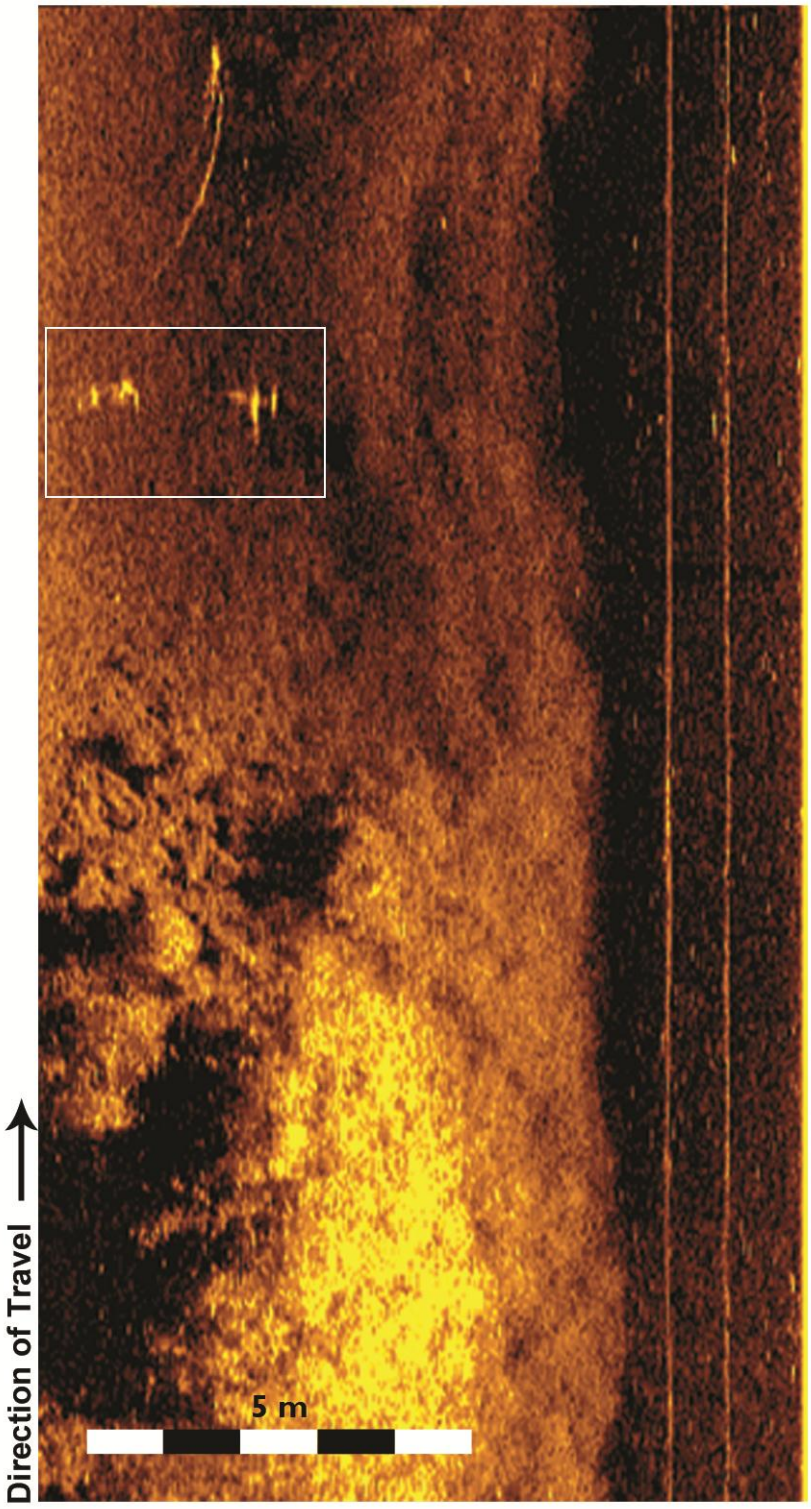

Figure 43: File 11Nov026, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

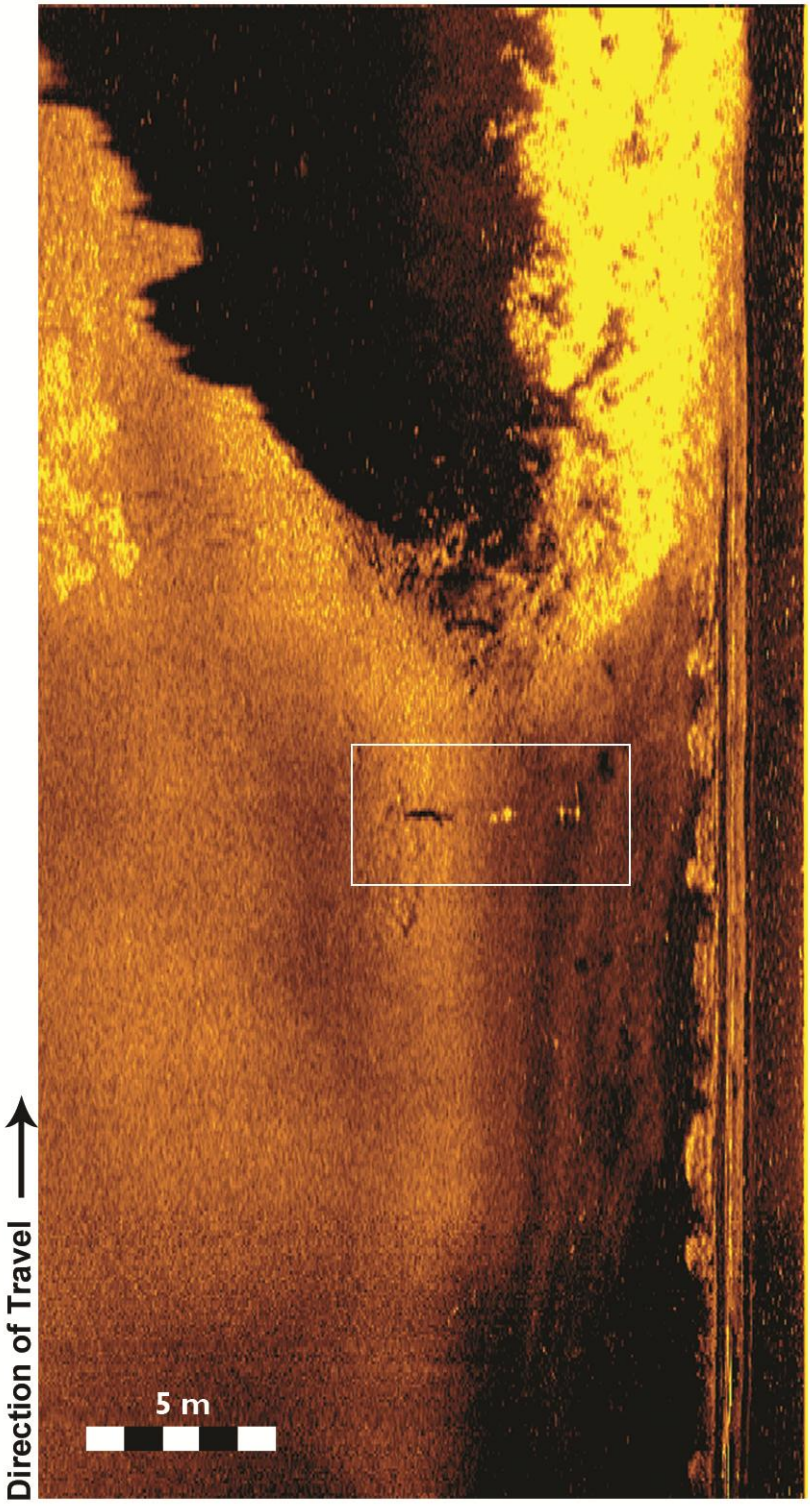

Figure 44: File 11Nov069, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

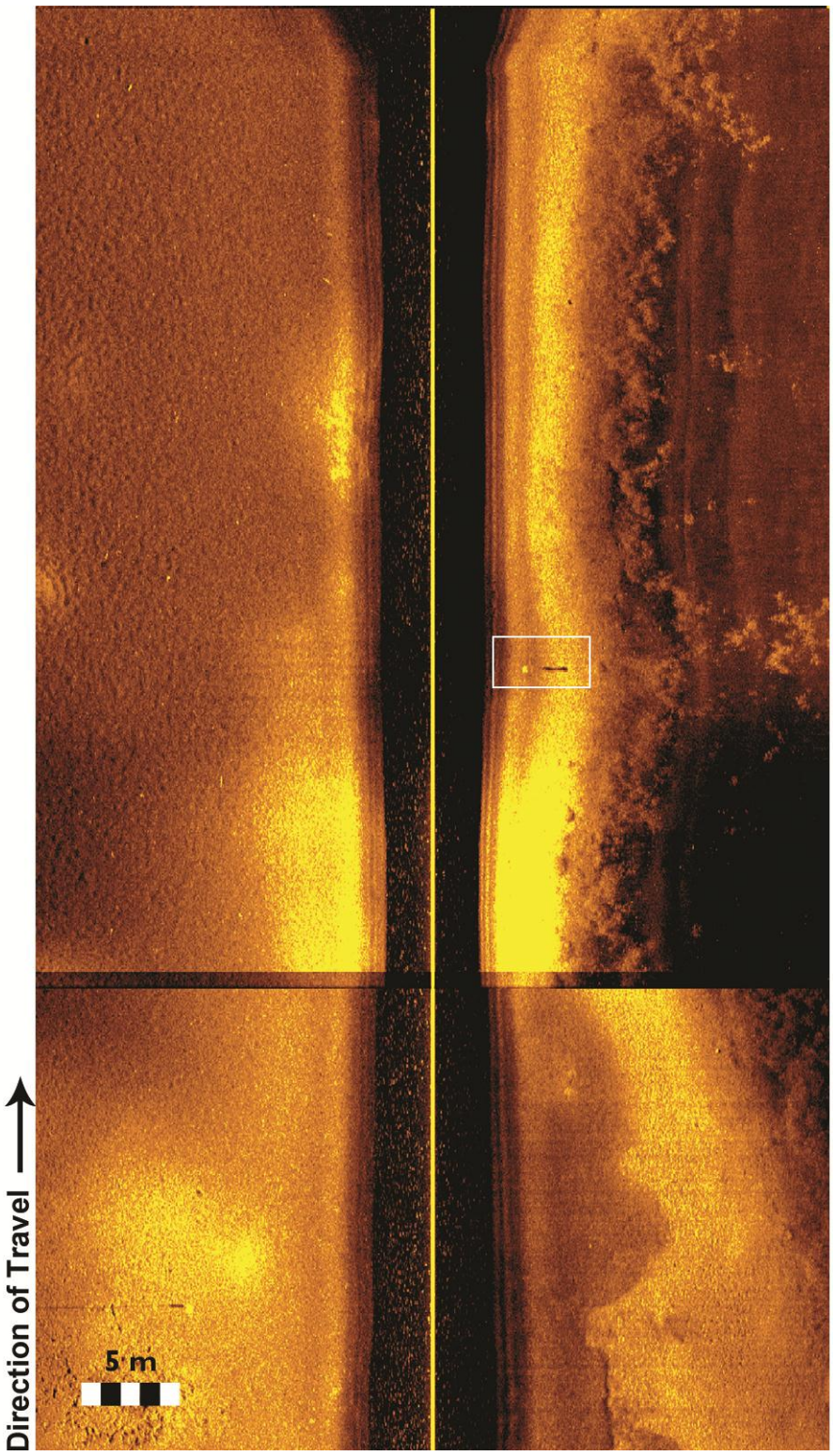

Figure 45: File 14Nov005, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "poor."

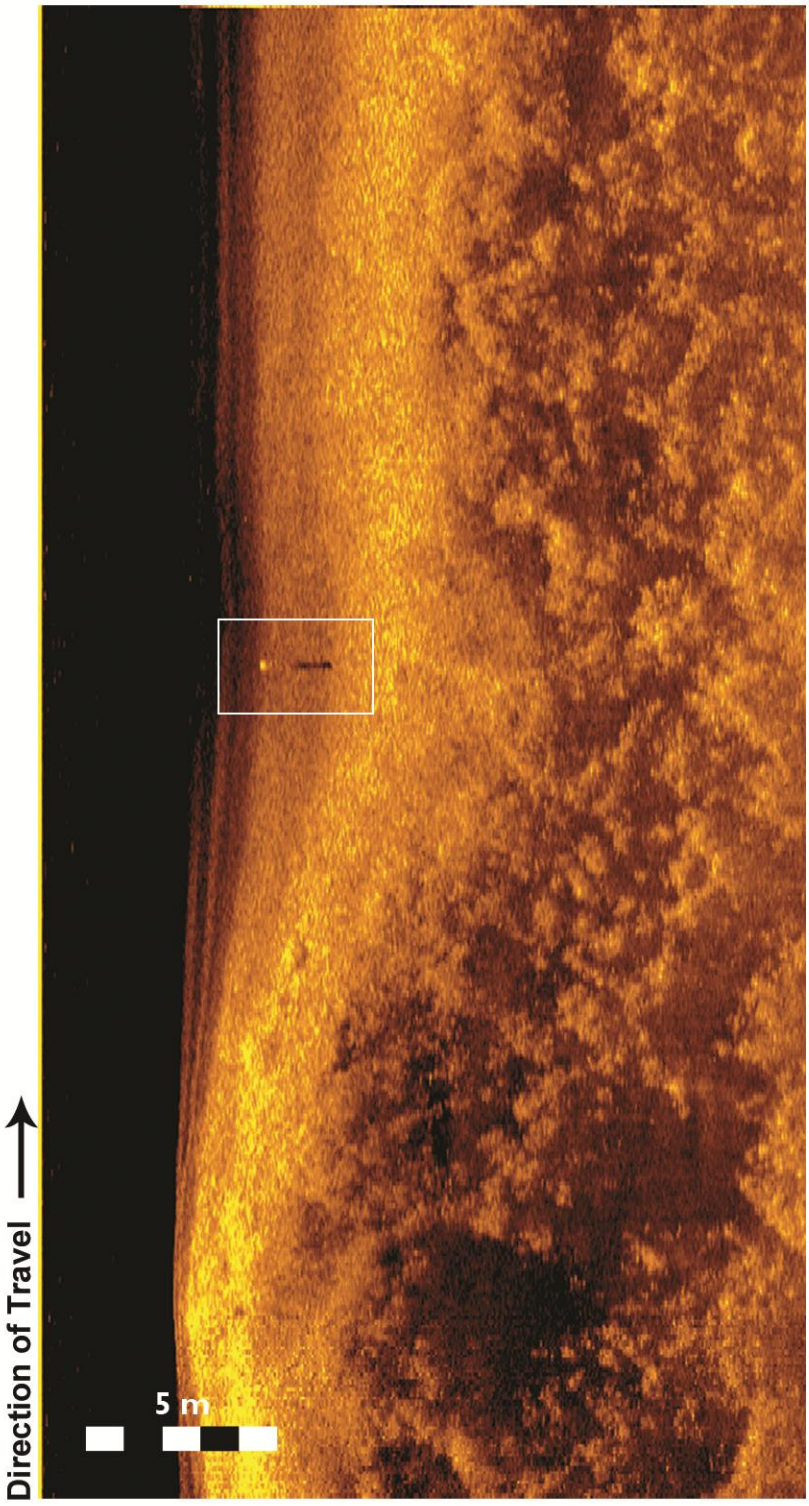

Figure 46: File 14Nov027, 1800 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "poor."

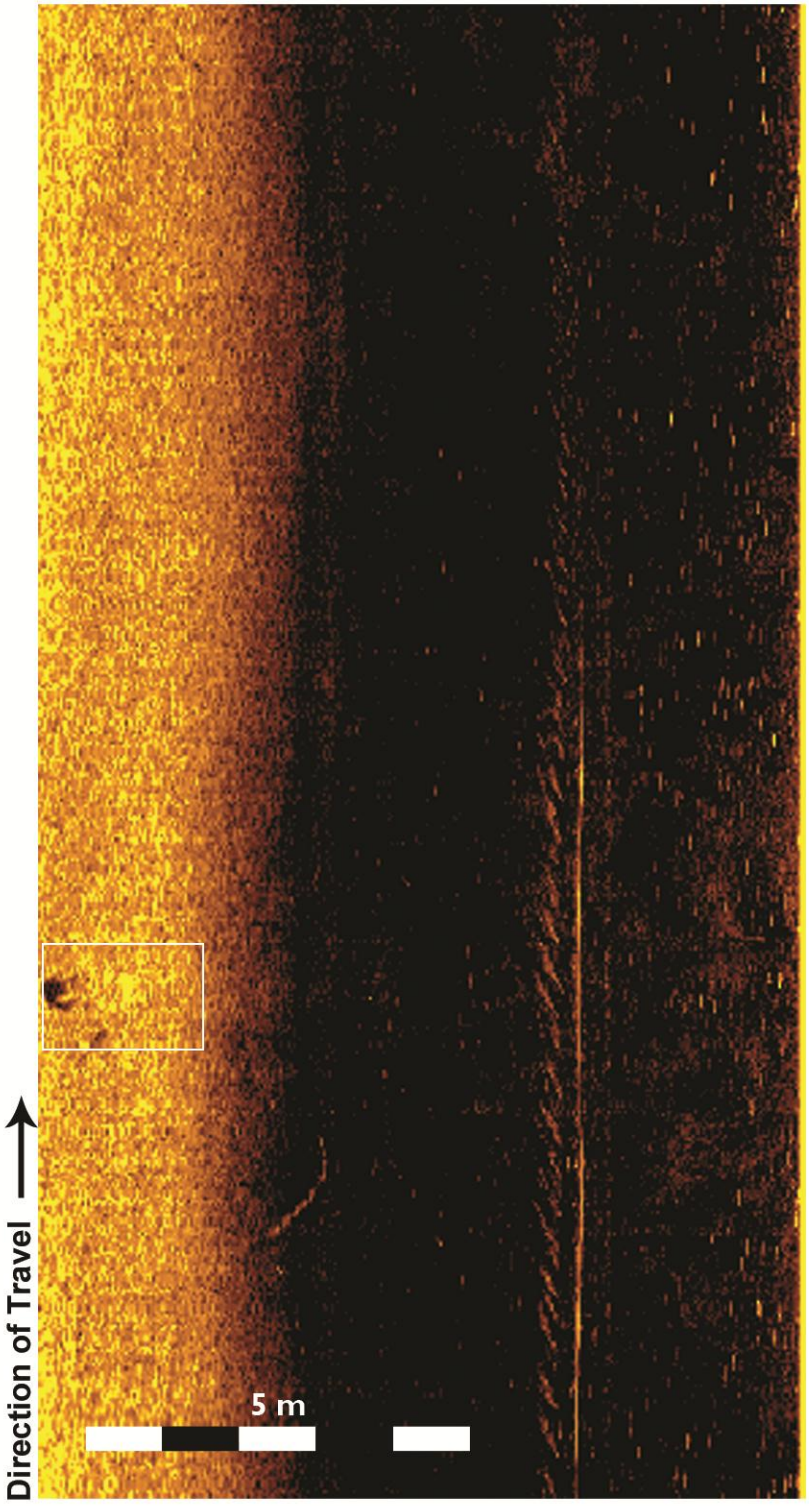

Figure 47: File 18Nov123, 900 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

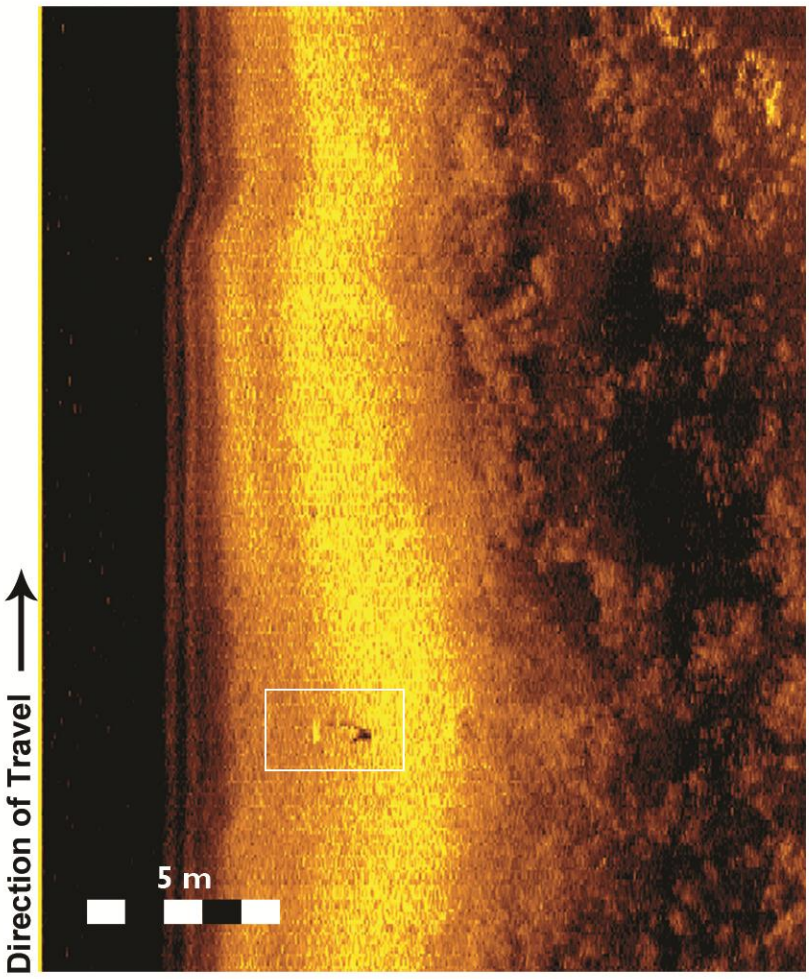

Figure 48: File 18Nov012, 900 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "poor."

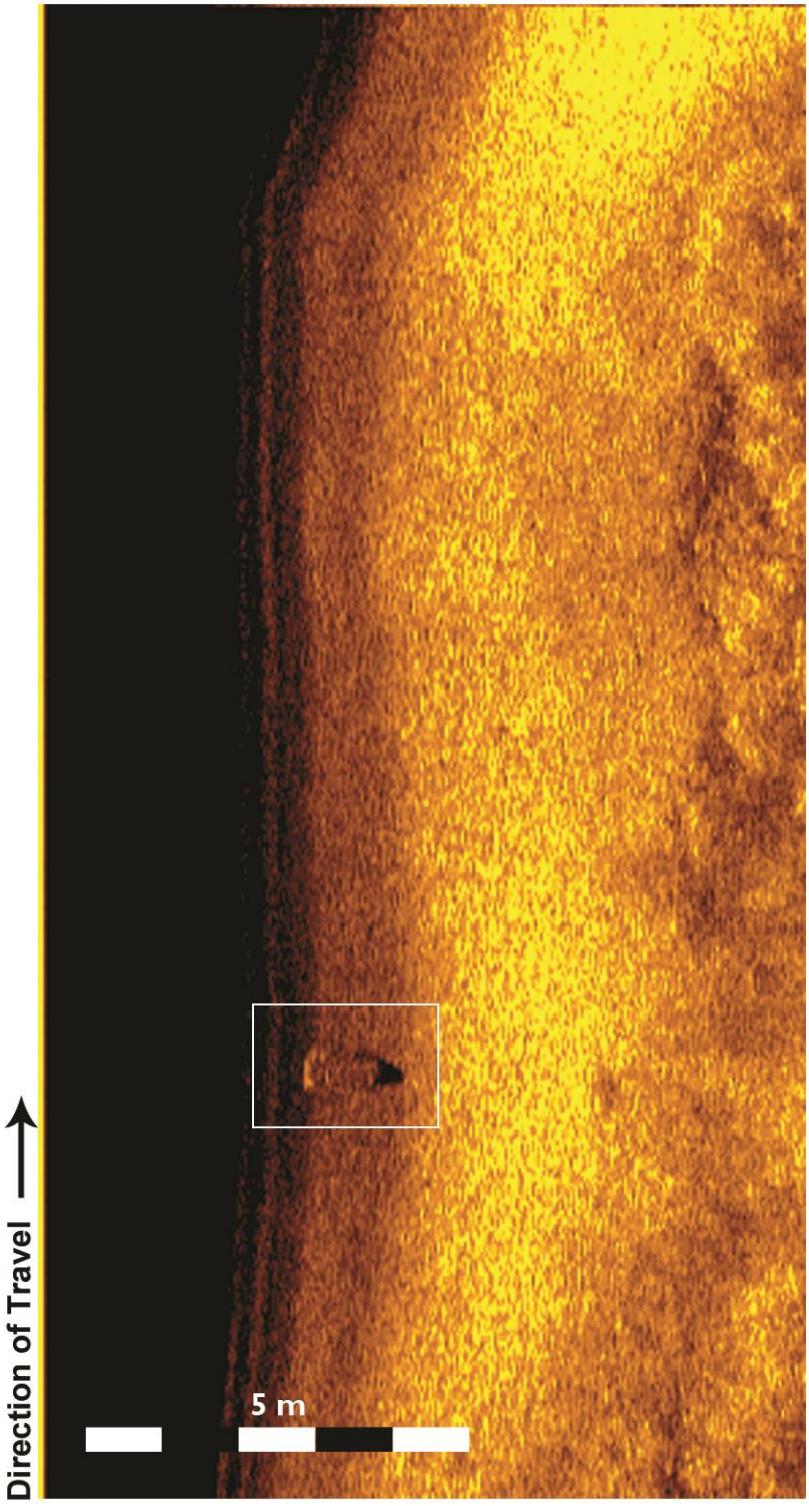

Figure 49: File 18Nov029, 1800 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "good."

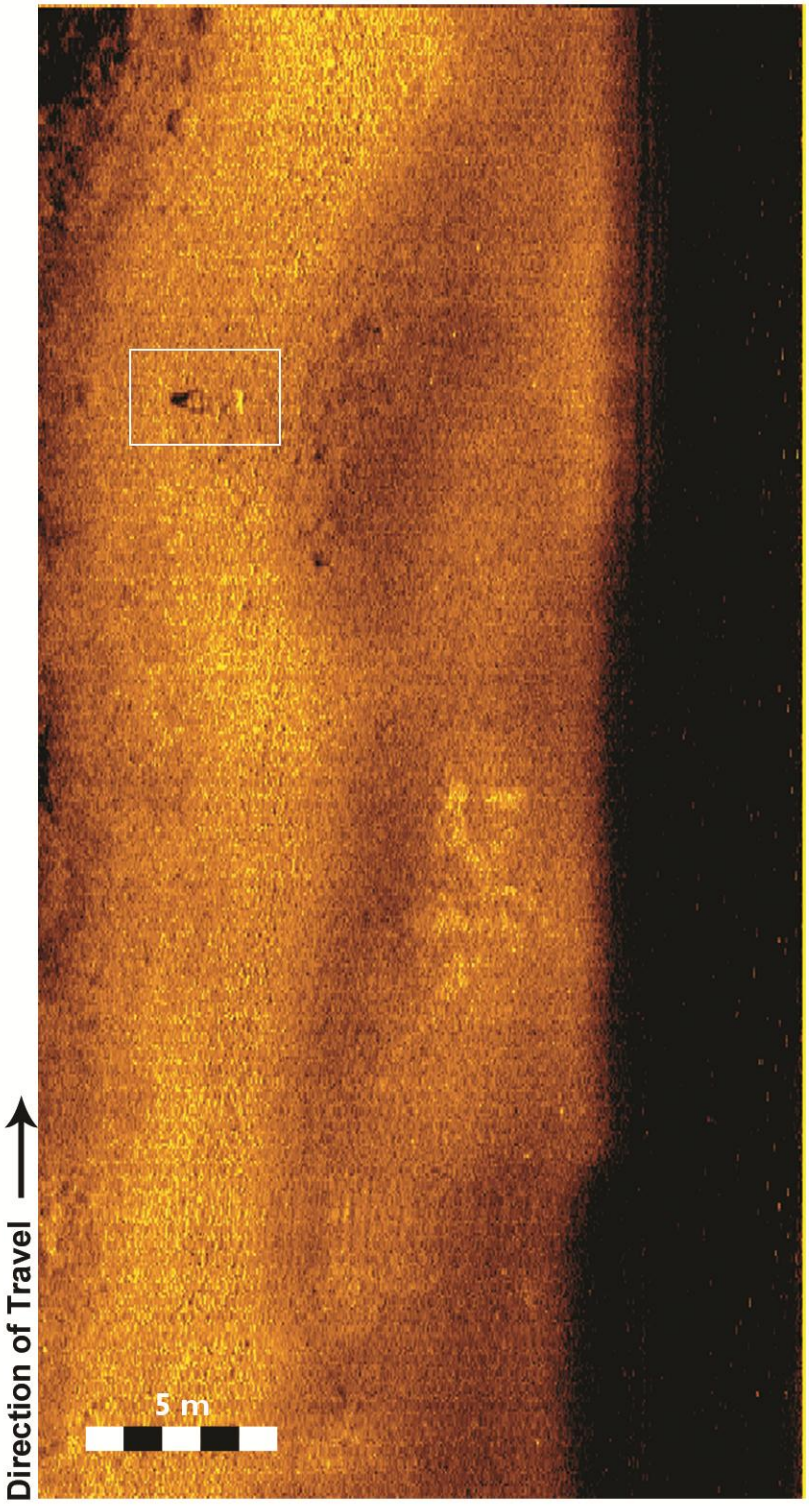

Figure 50: File 18Nov031, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

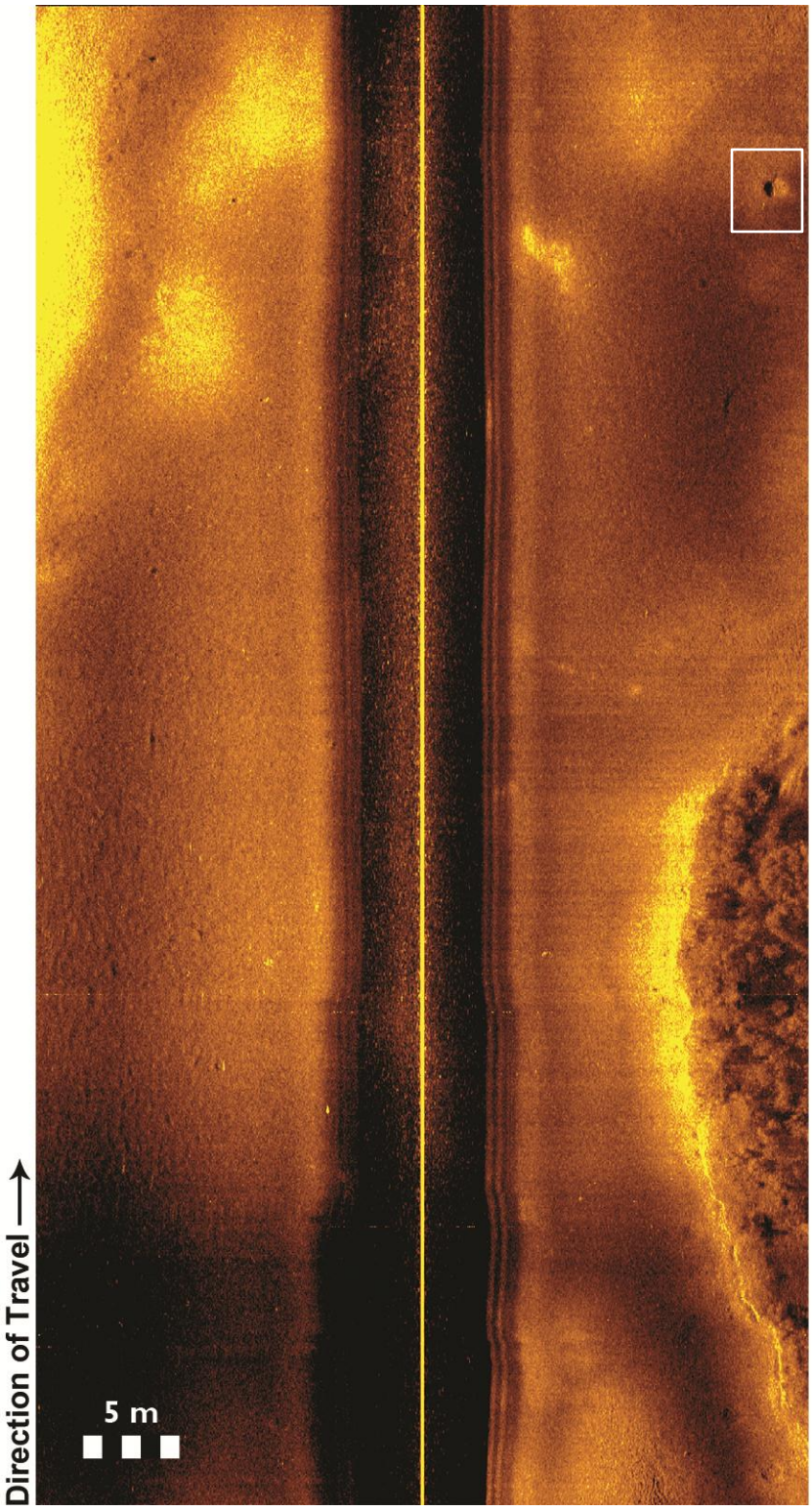

Figure 51: File 27Jan009, 900 kHz, 20 m, acoustic signals transmitted out of both sides of the towfish. Pig carcass possibly detected and scored as "poor."

APPENDIX C: SONAR IMAGES FROM PIG 1B

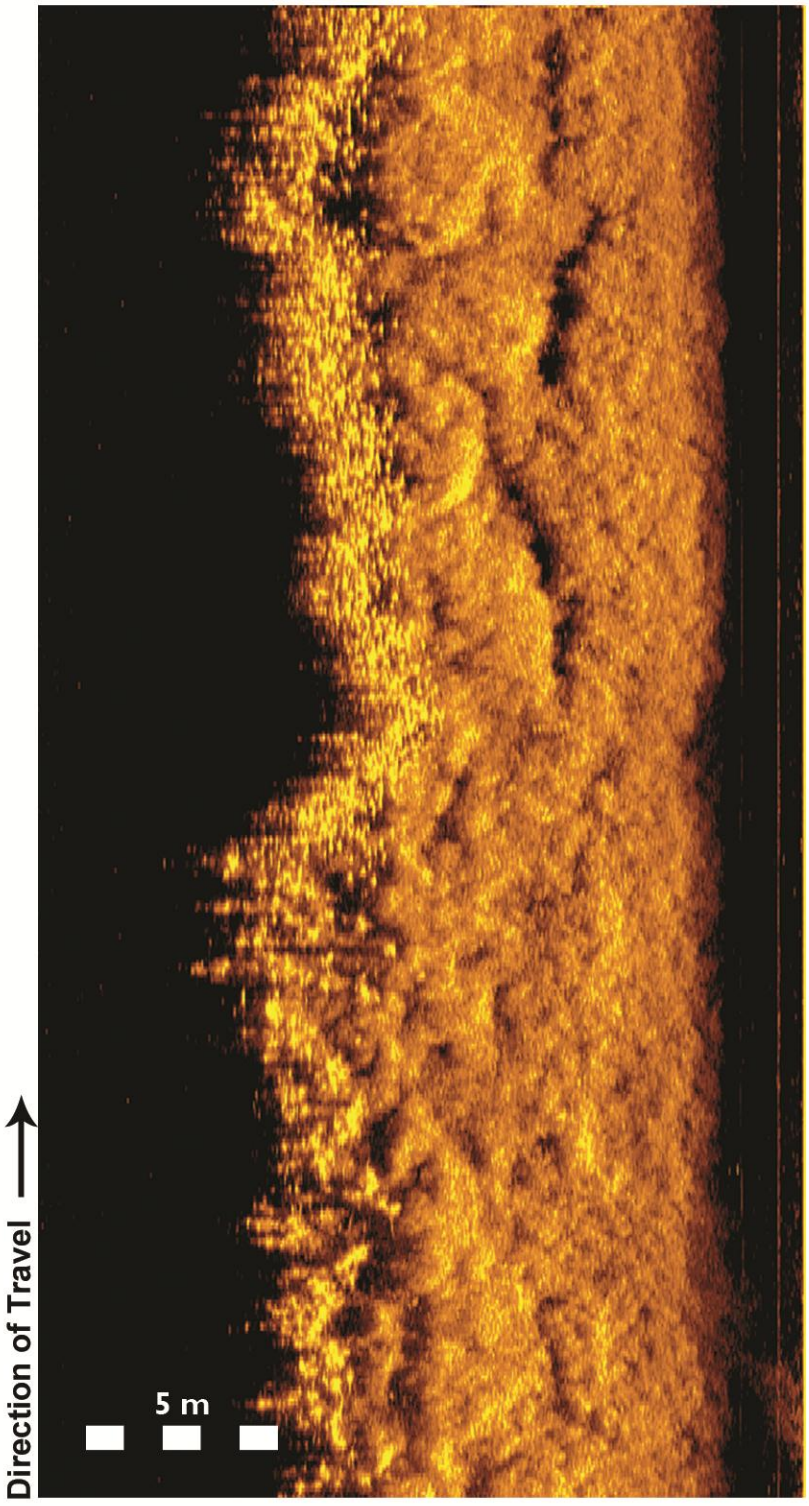

Figure 52: 31Oct114, 900 kHz, 20 m, acoustic signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

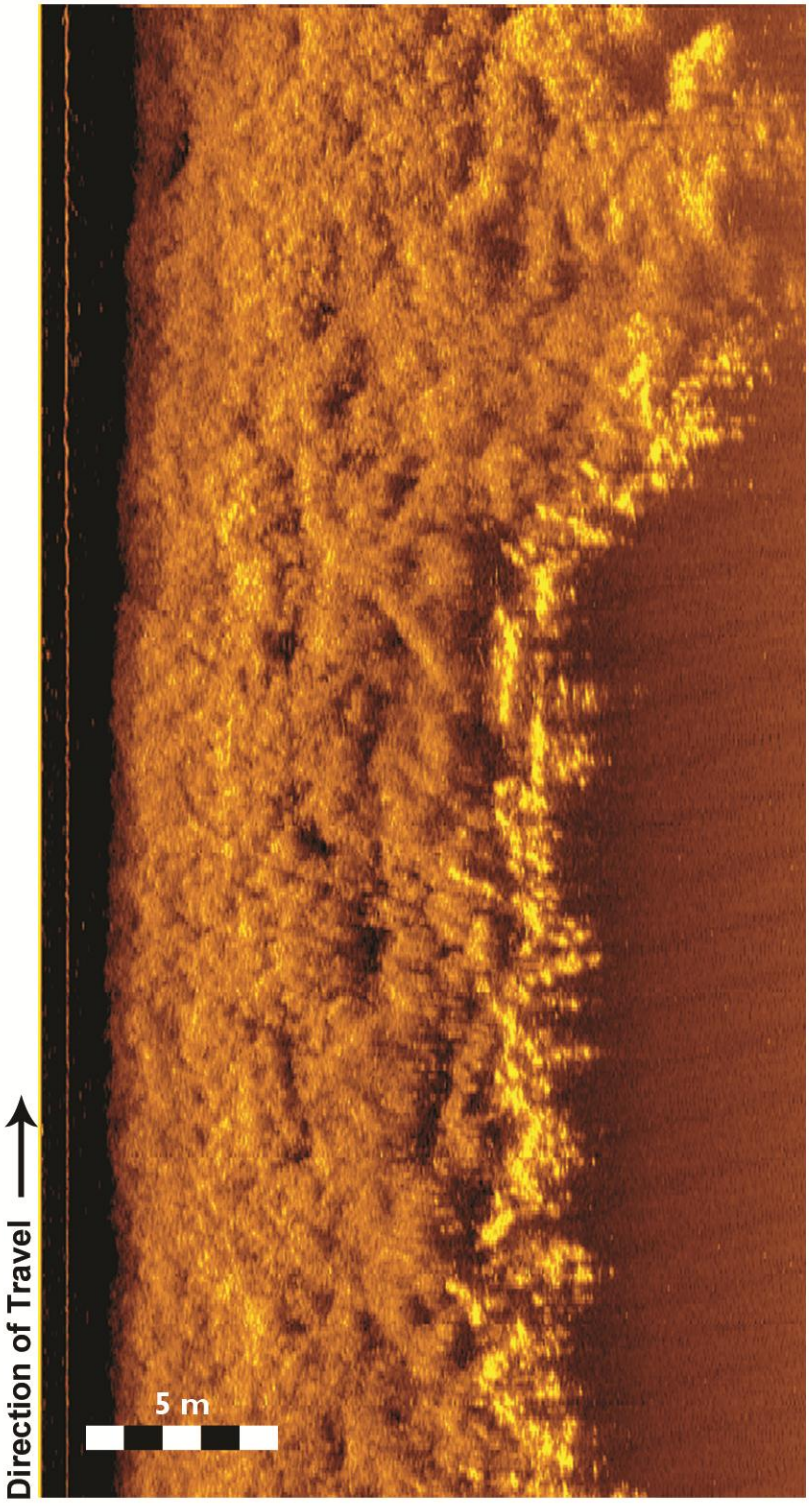

Figure 53: File 31Oct164, 1800 kHz, 20 m, acoustic signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

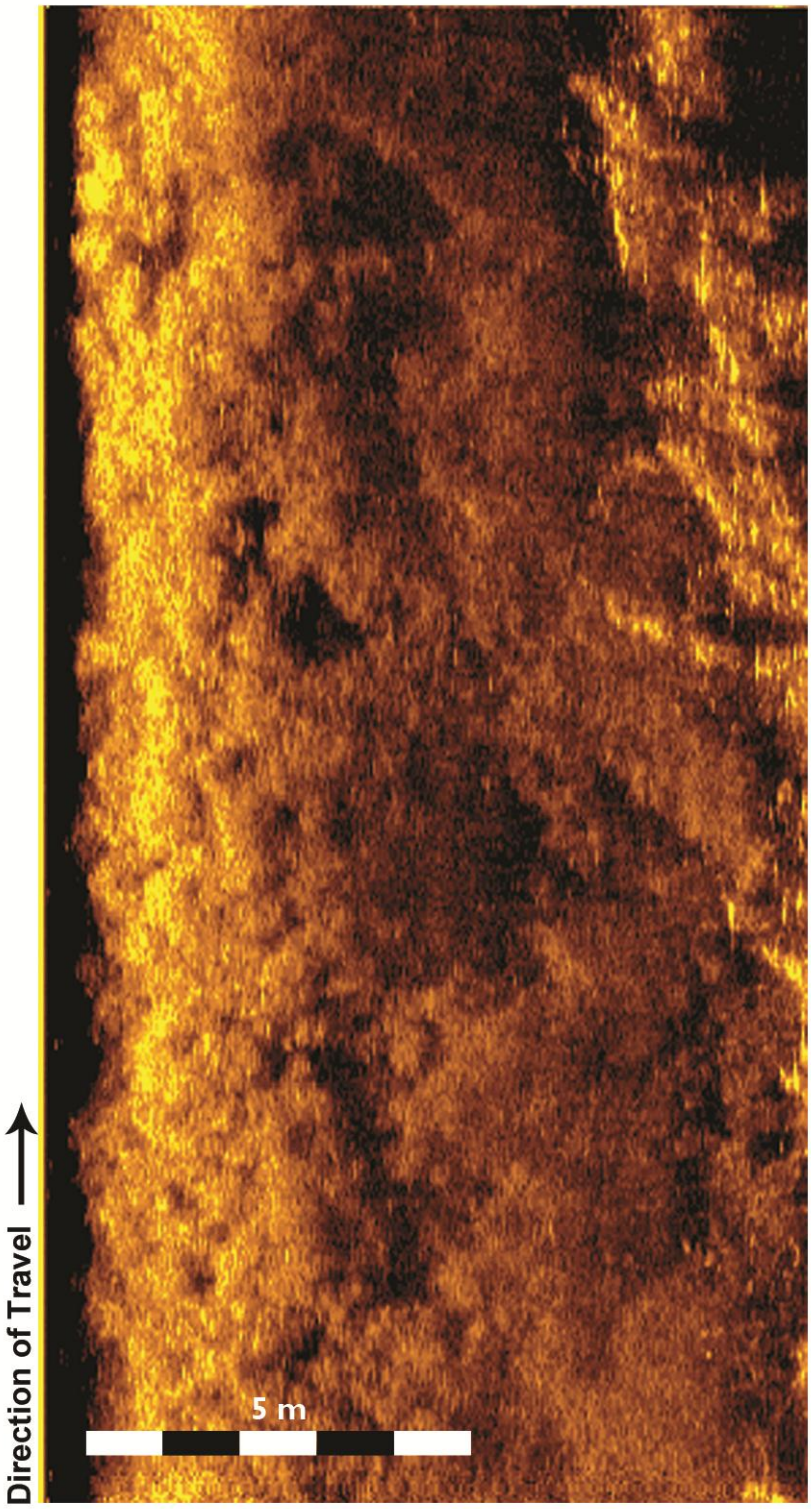

Figure 54: File 01Nov088, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

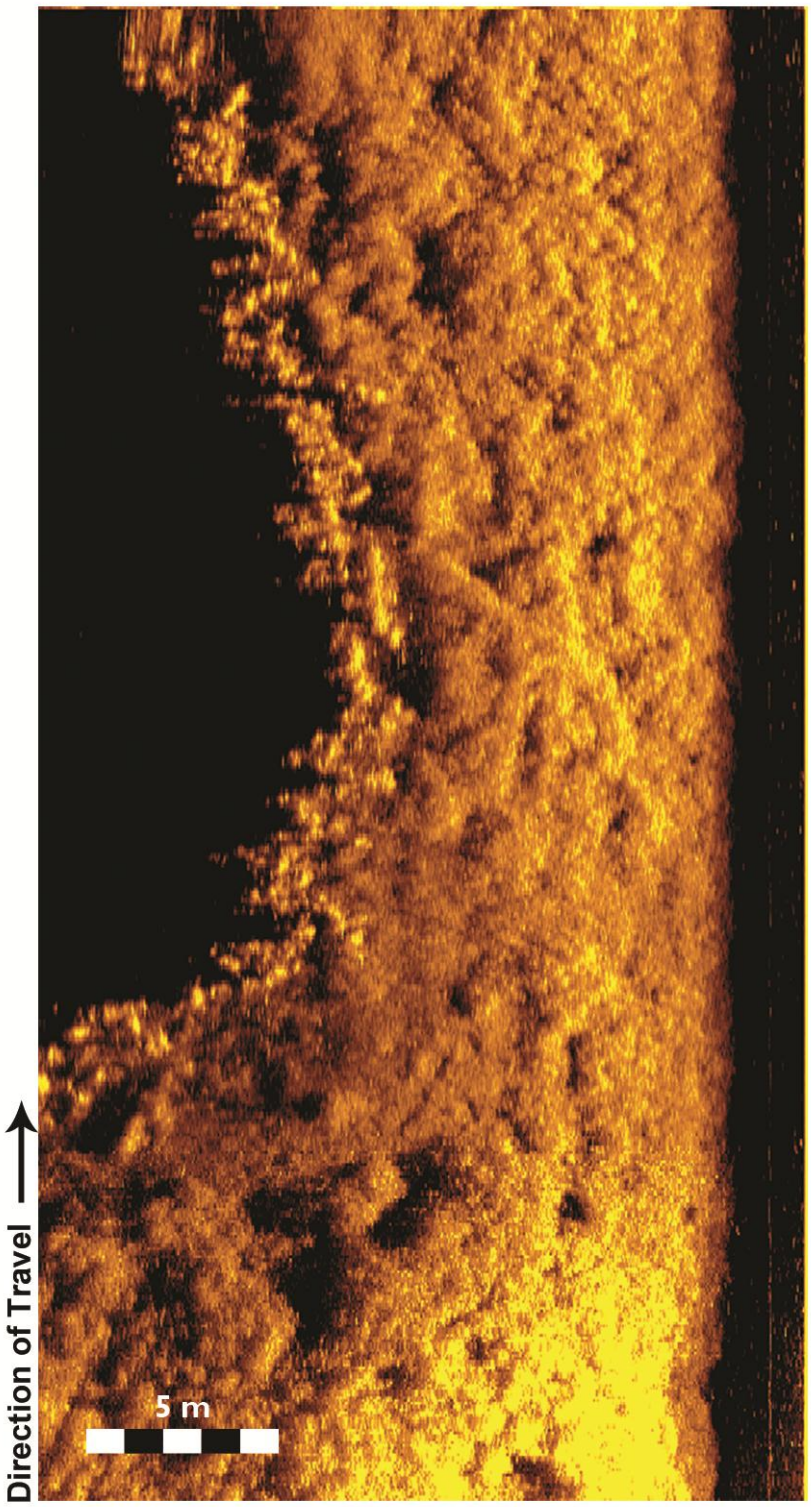

Figure 55: File 01Nov136, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

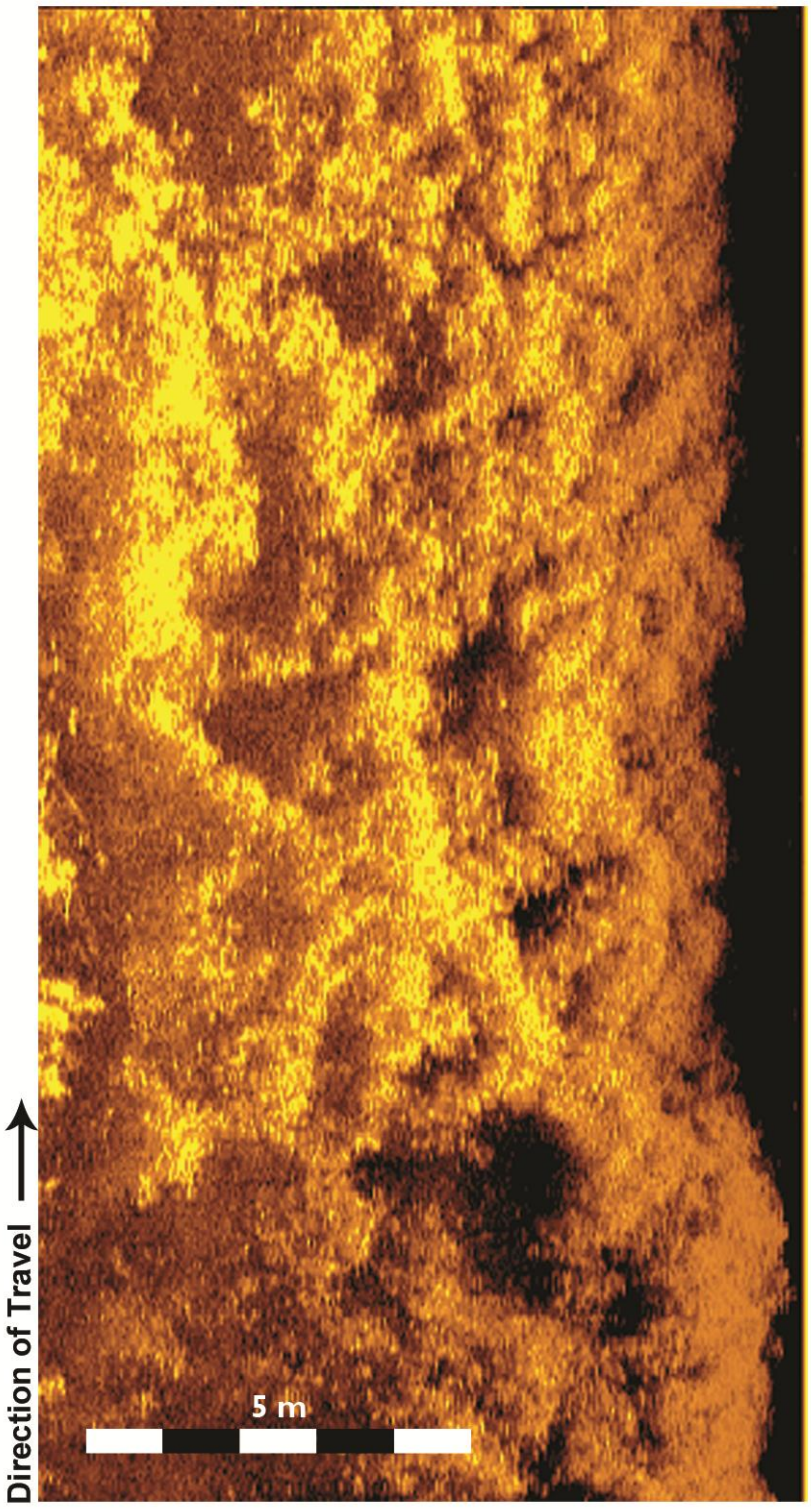

Figure 56: File 01Nov119, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

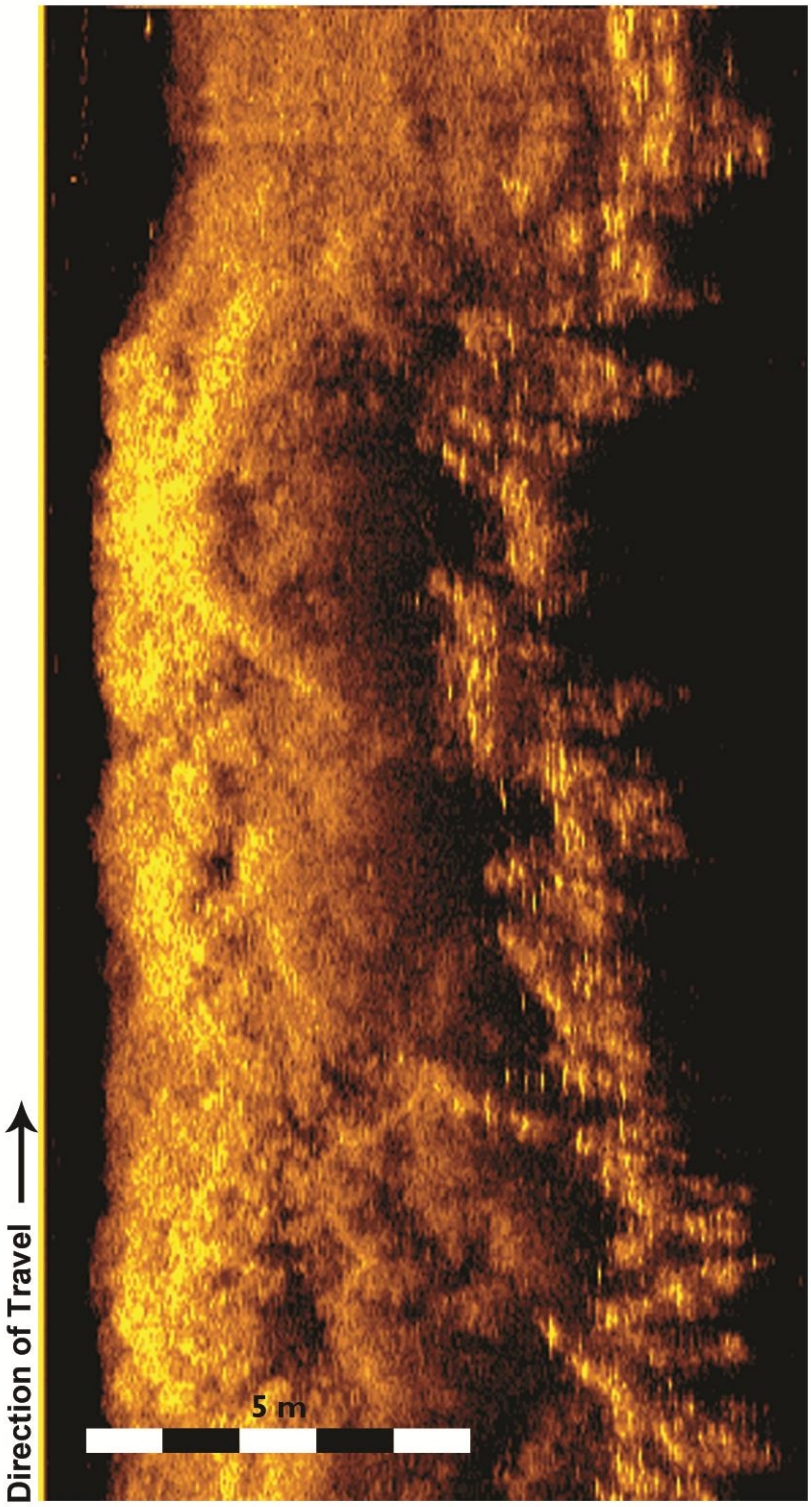

Figure 57: File 04Nov076, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

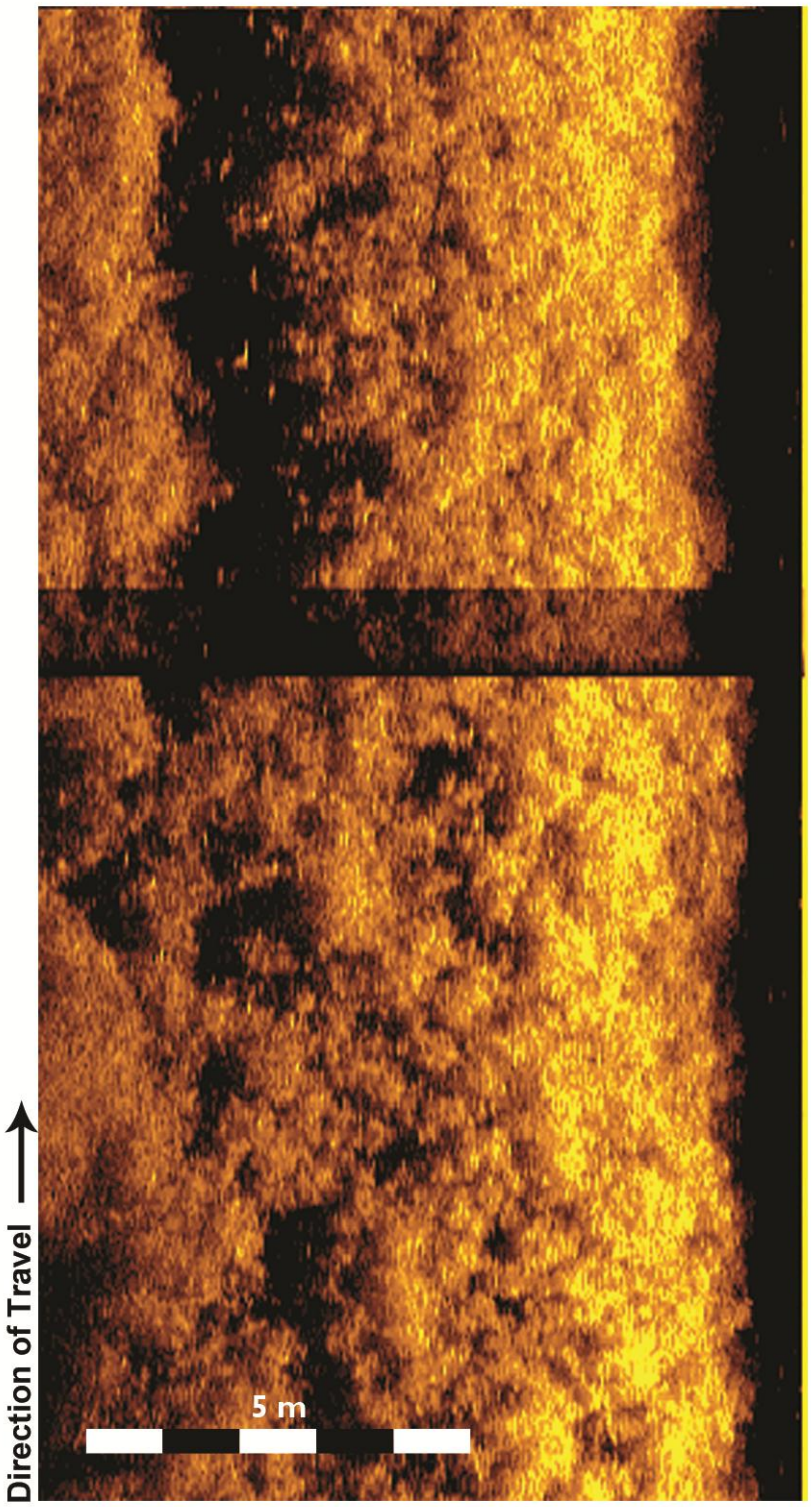

Figure 58: File 04Nov113, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

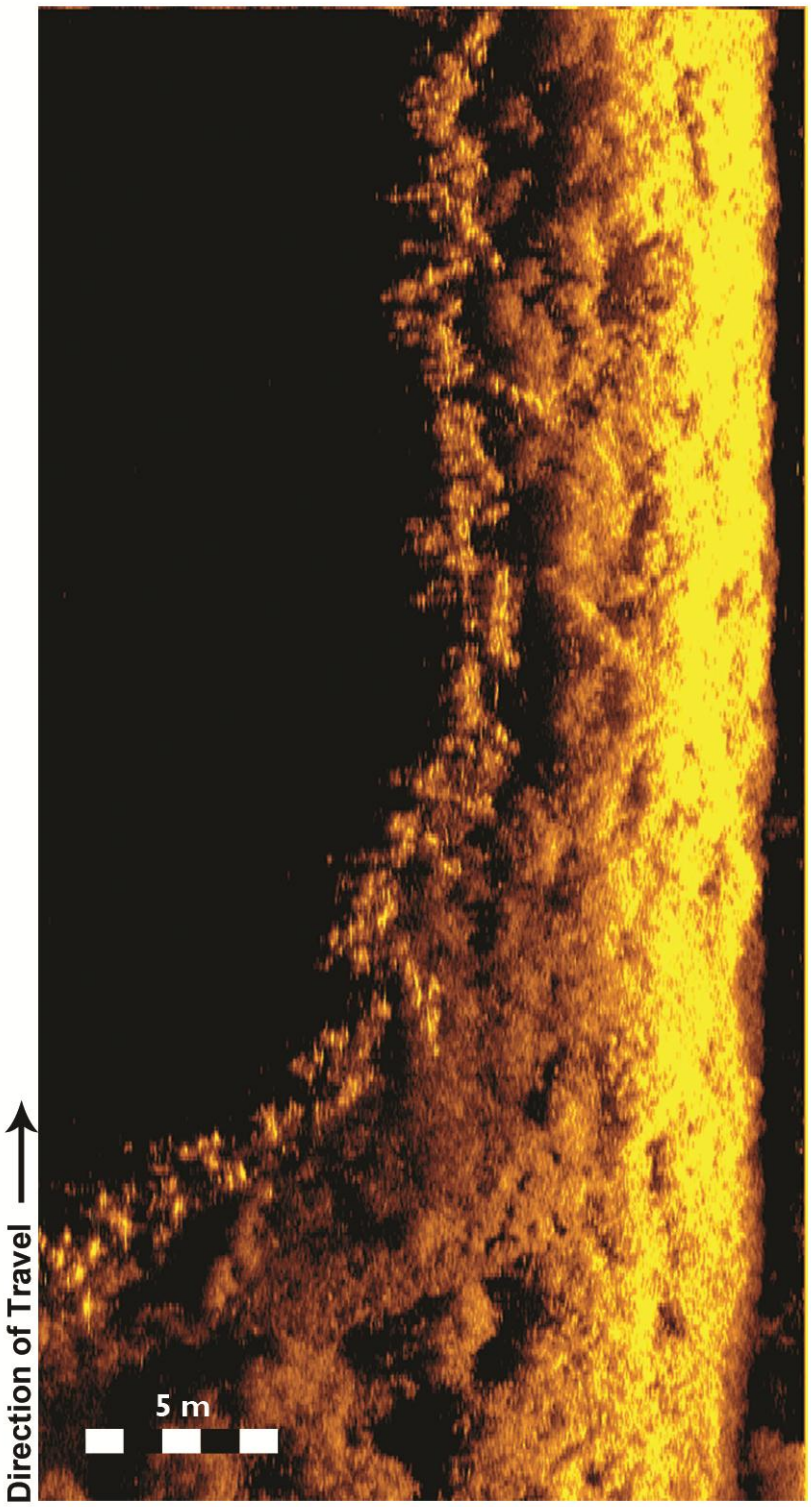

Figure 59: File 04Nov132, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

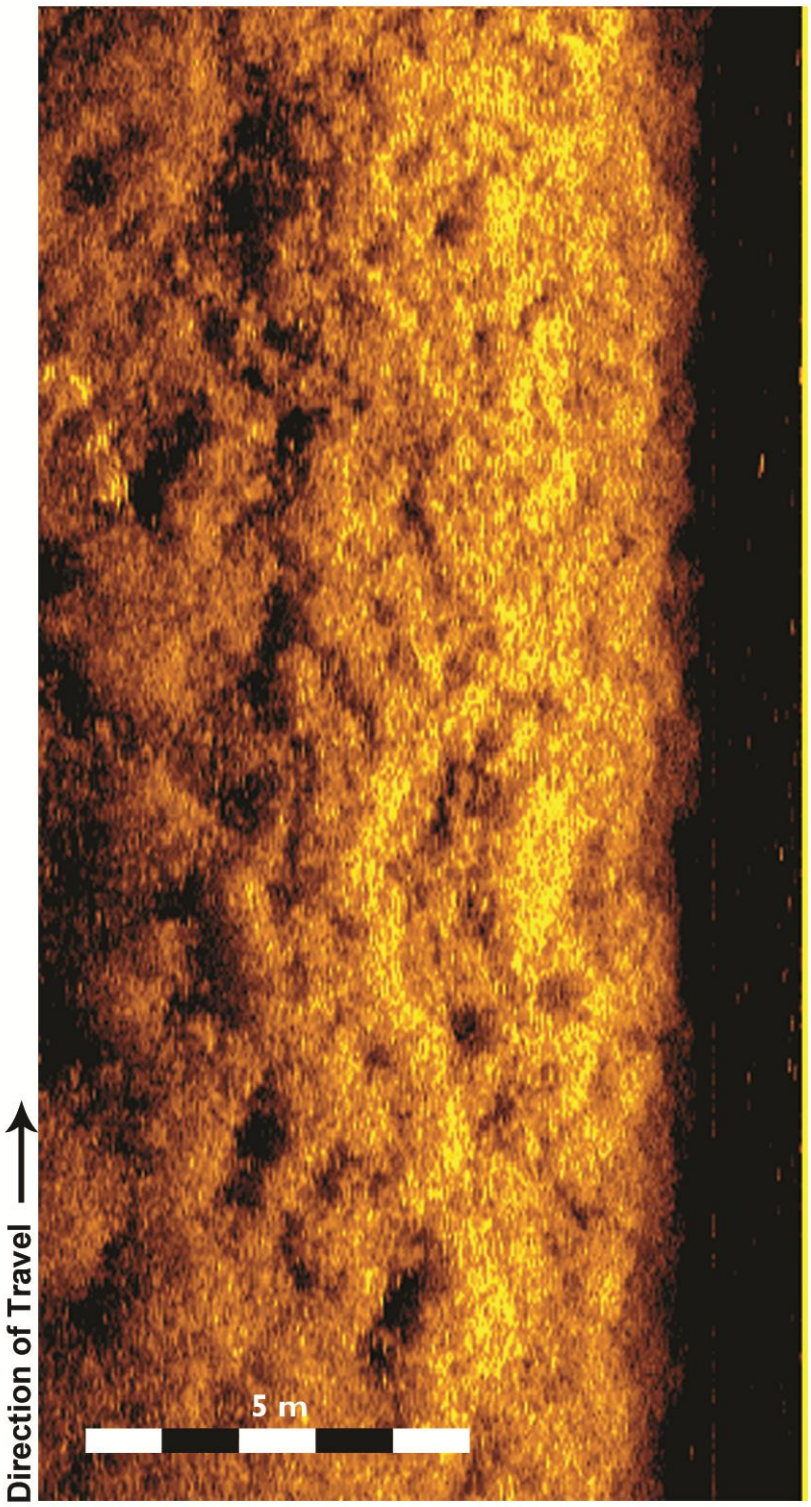

Figure 60: File 11Nov048, 900 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

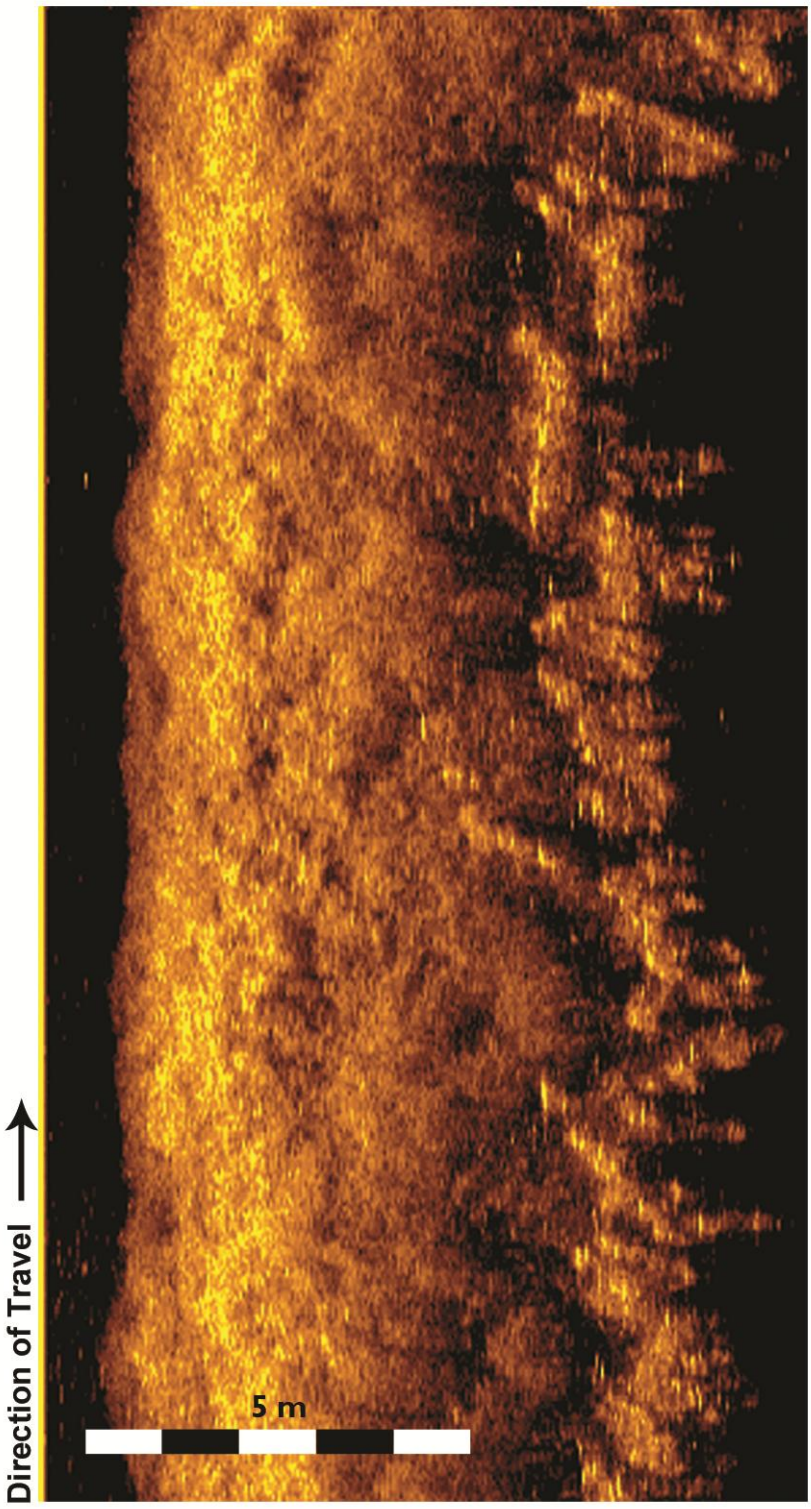

Figure 61: File 11Nov054, 1800 kHz, m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

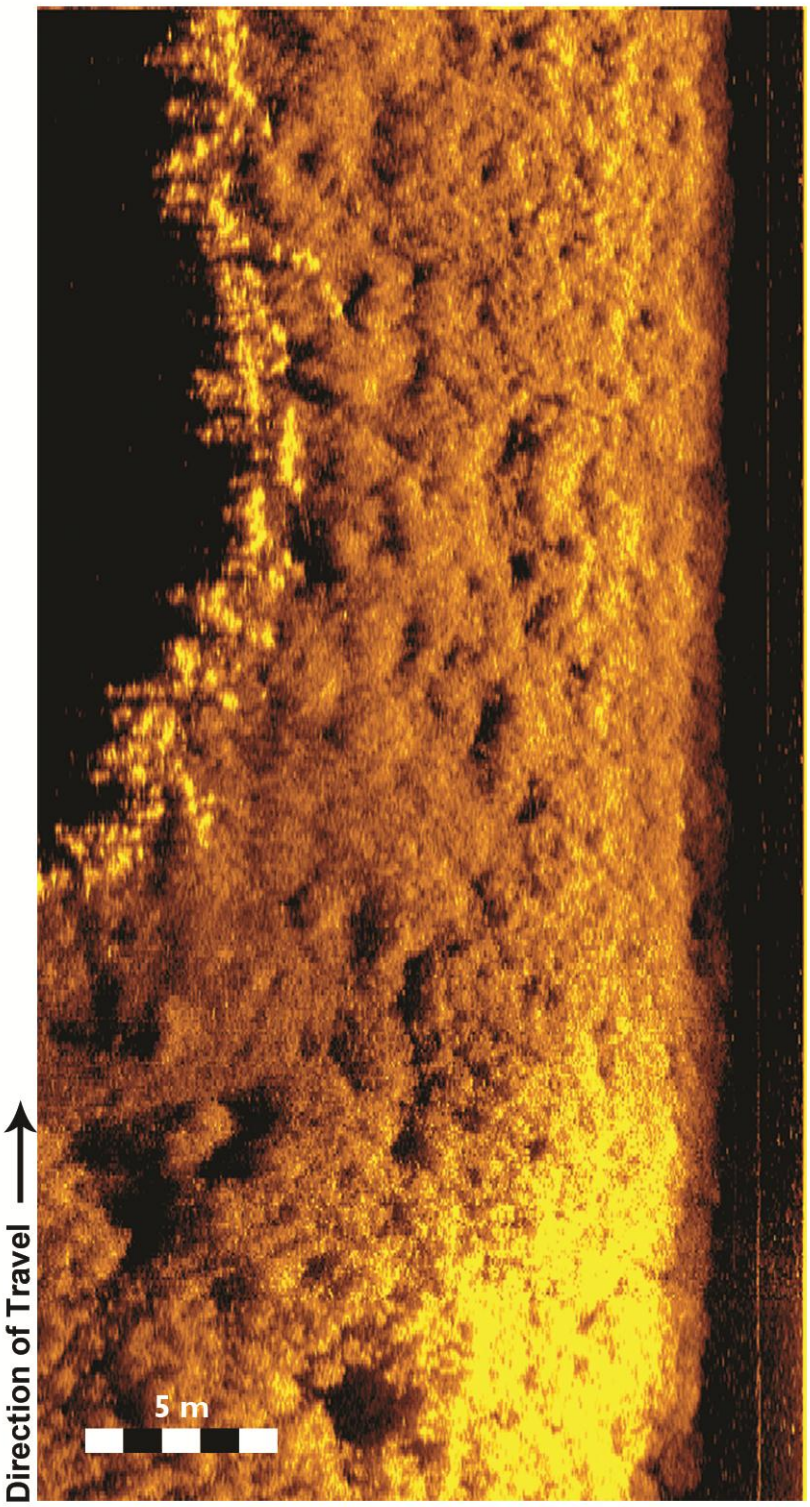

Figure 62: File 11Nov057, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

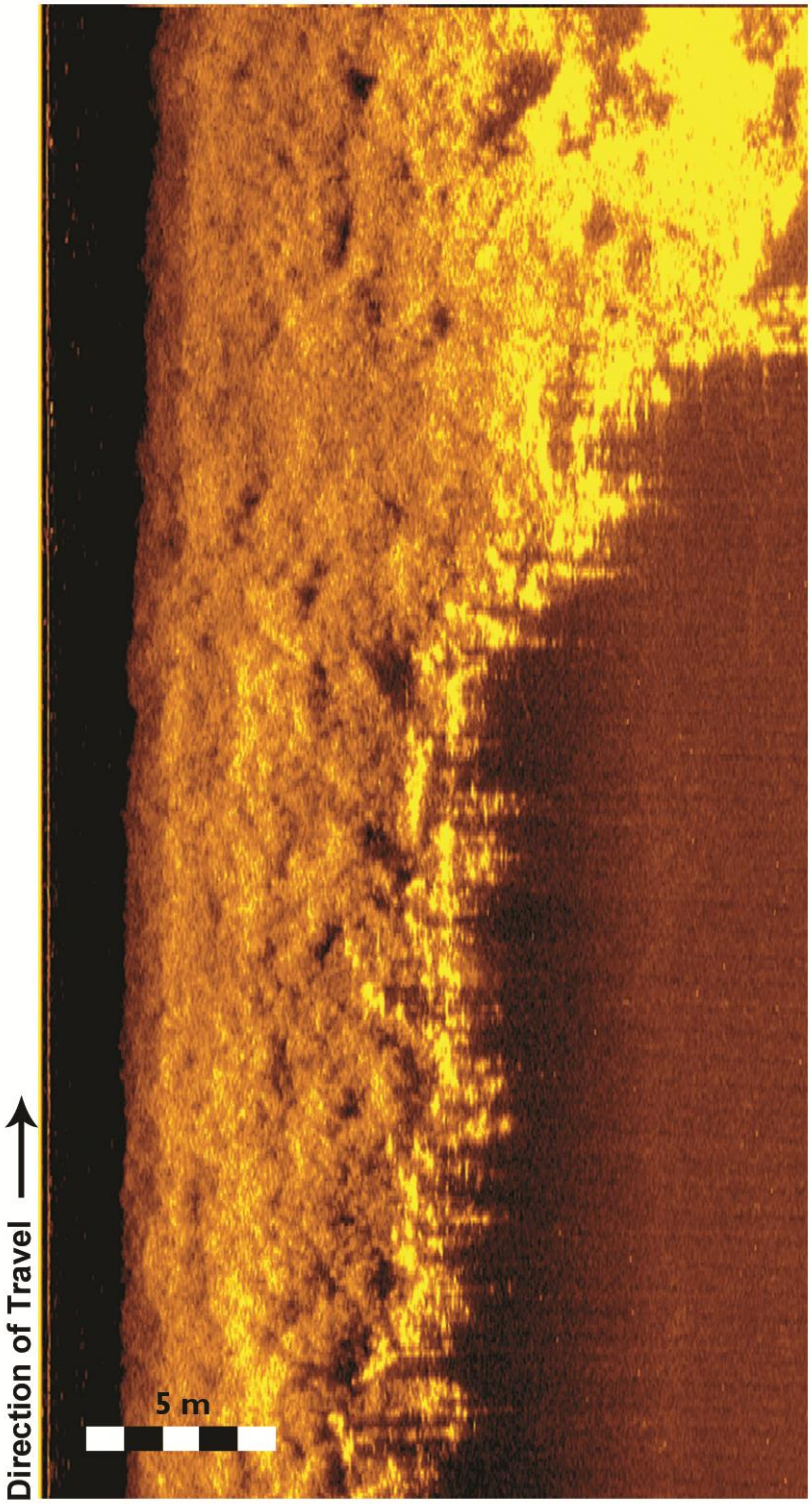

Figure 63: File 14Nov094, 900 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

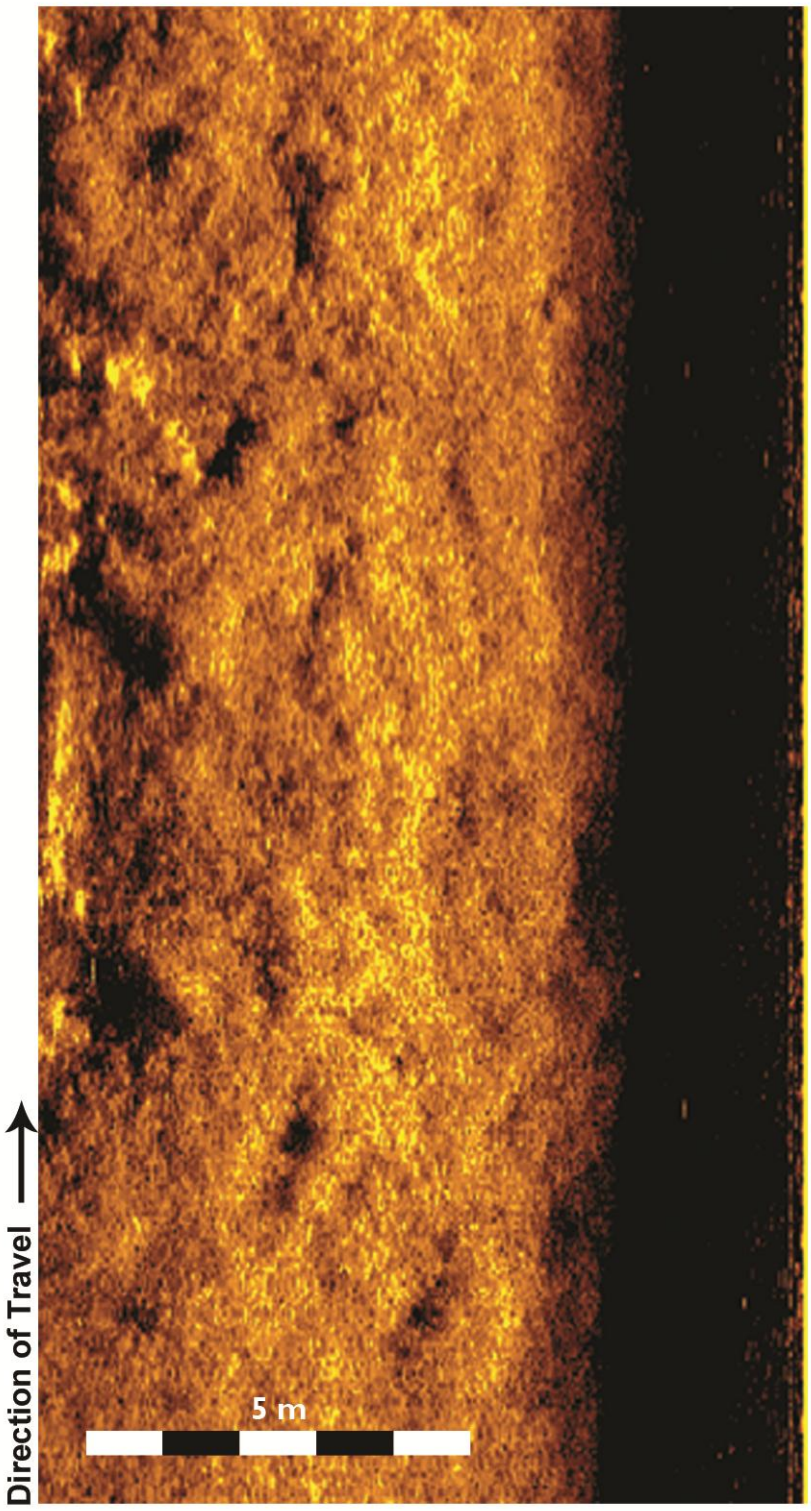

Figure 64: File 14Nov099, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

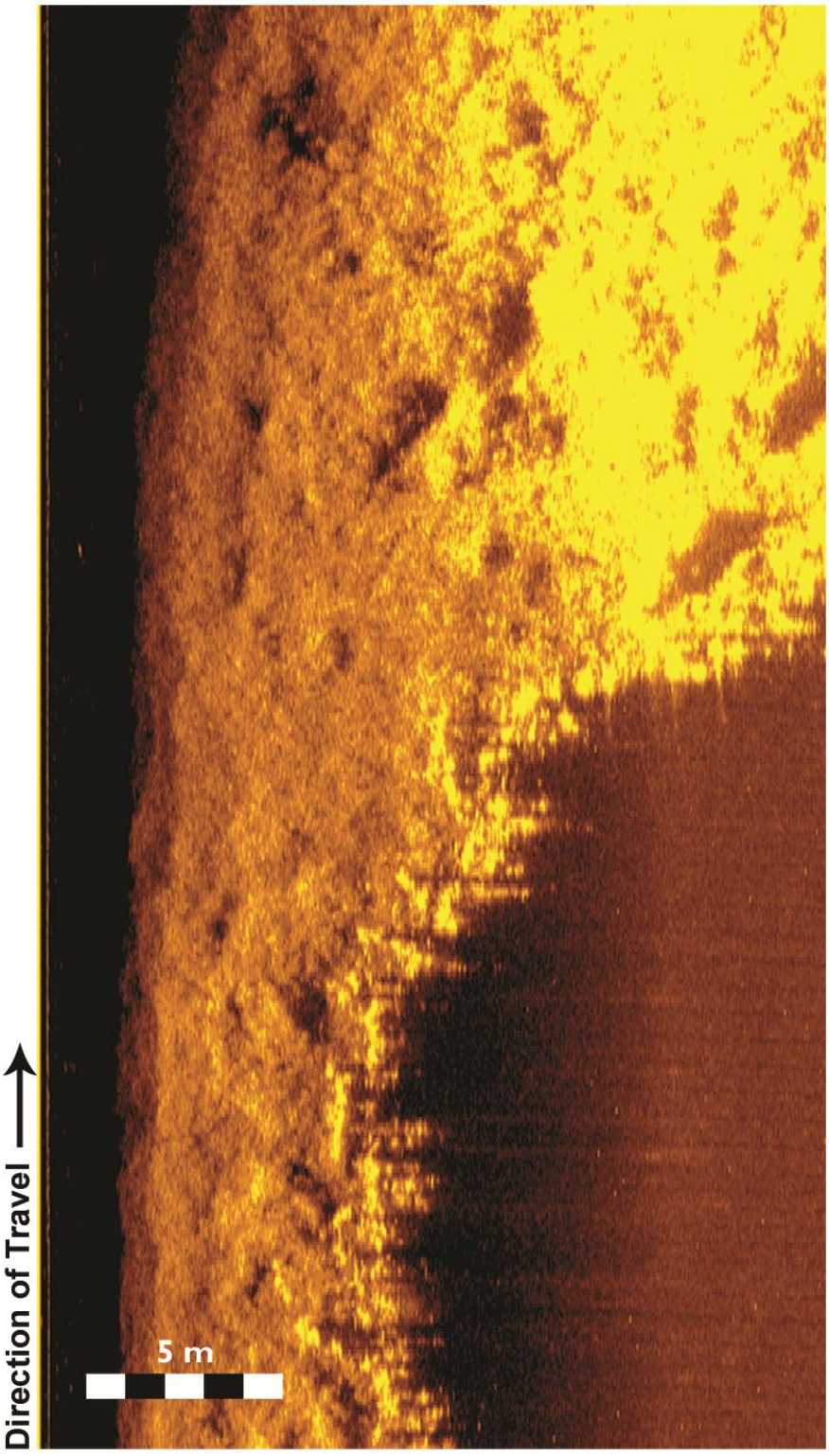

Figure 65: File 14Nov087, 1800 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

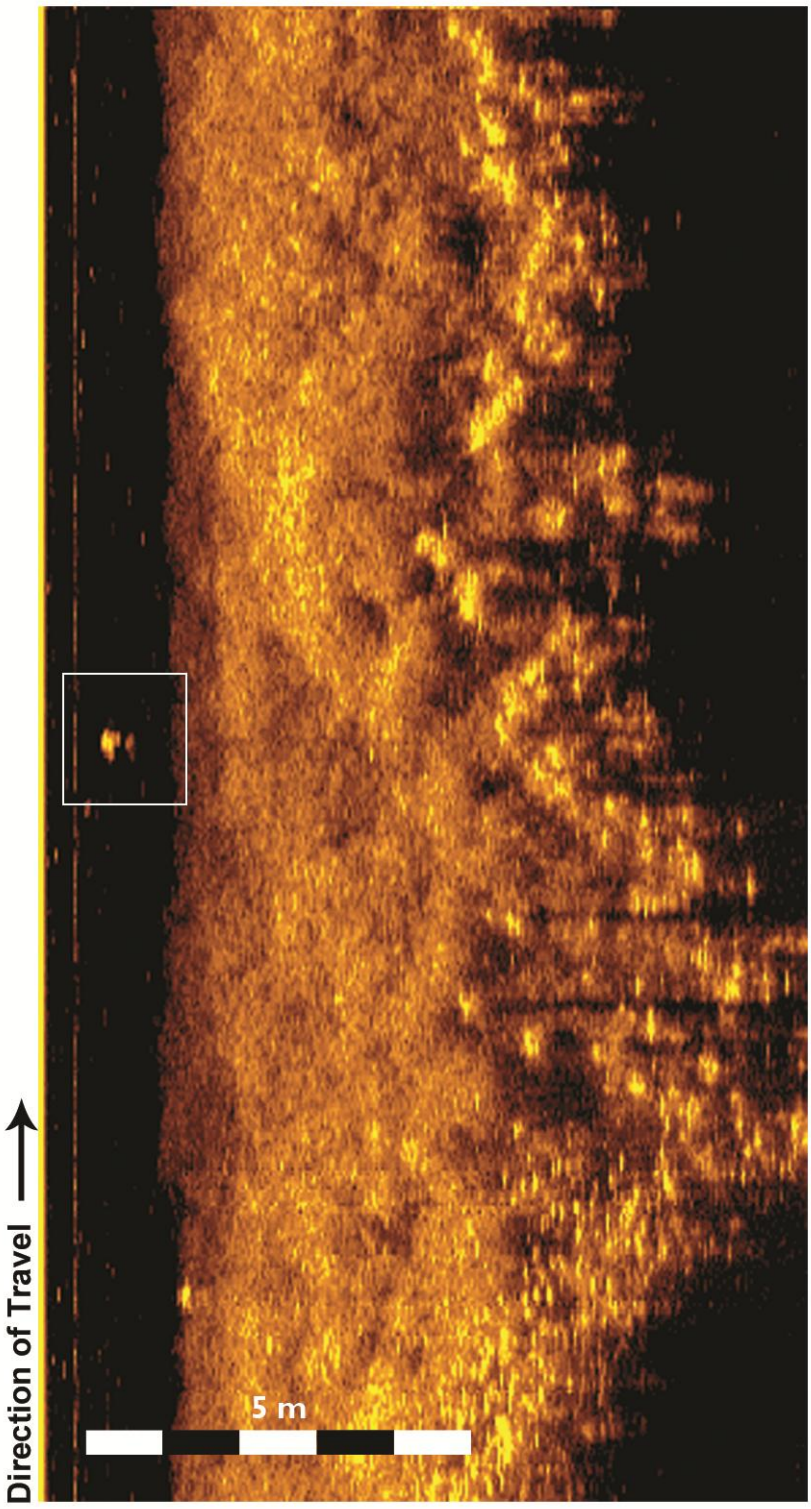

Figure 66: File 18Nov153, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "poor."

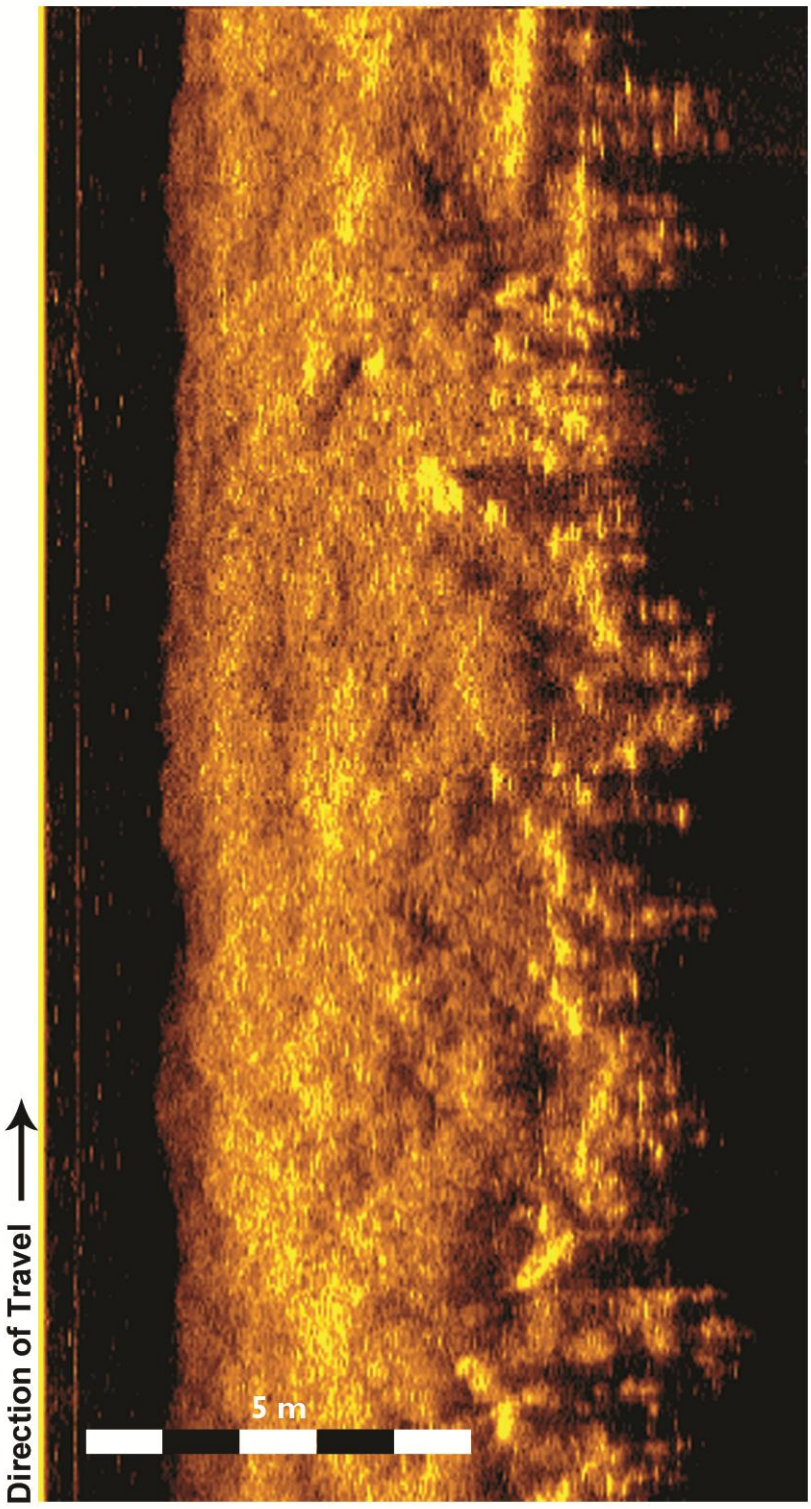

Figure 67: File 18Nov142, 1800 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

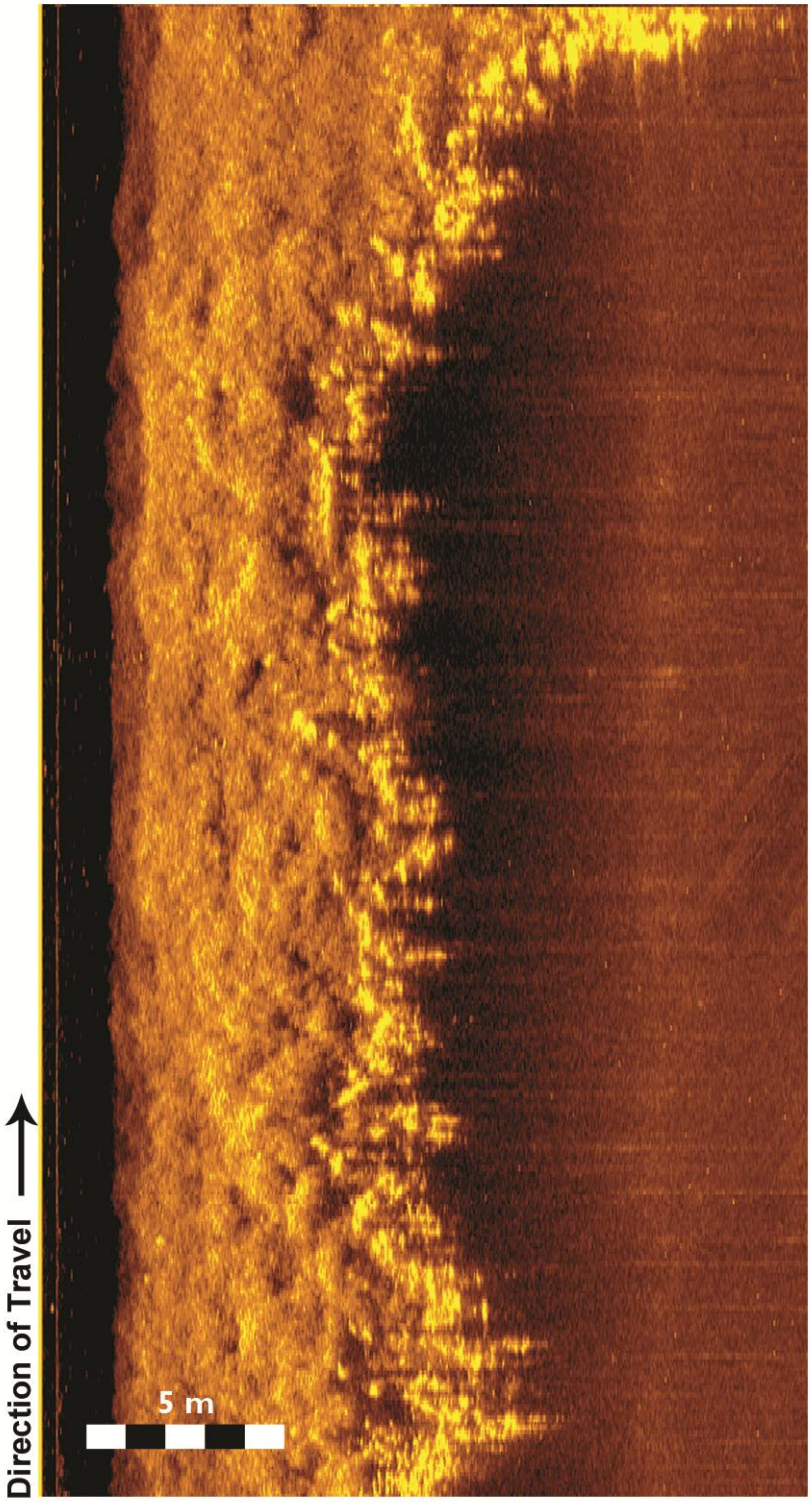

Figure 68: File 18Nov133, 1800 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

APPENDIX D: SONAR IMAGES FROM PIG 1C

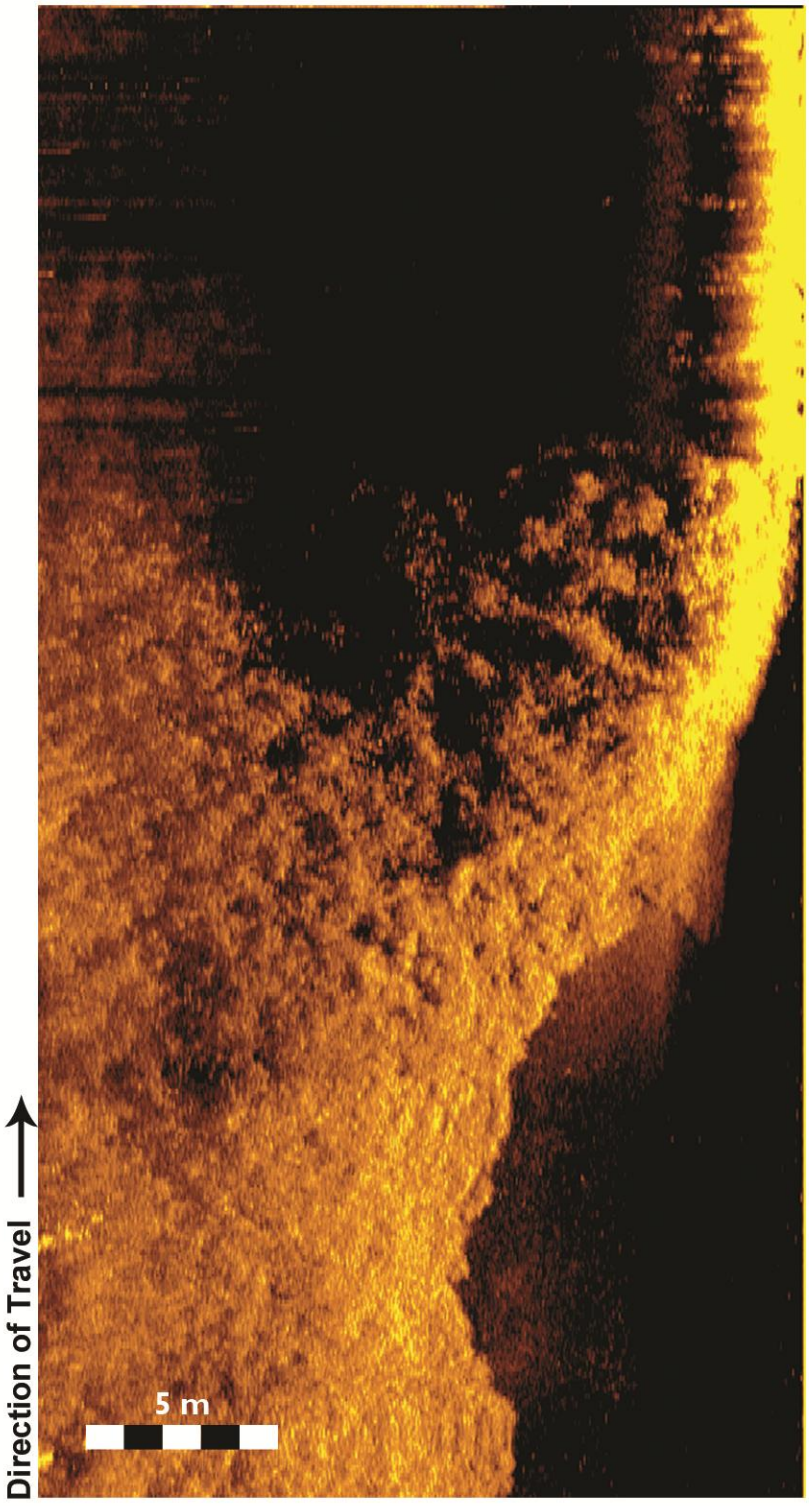

Figure 69: File 31Oct106, 900 kHz, 20 m, acoustic signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

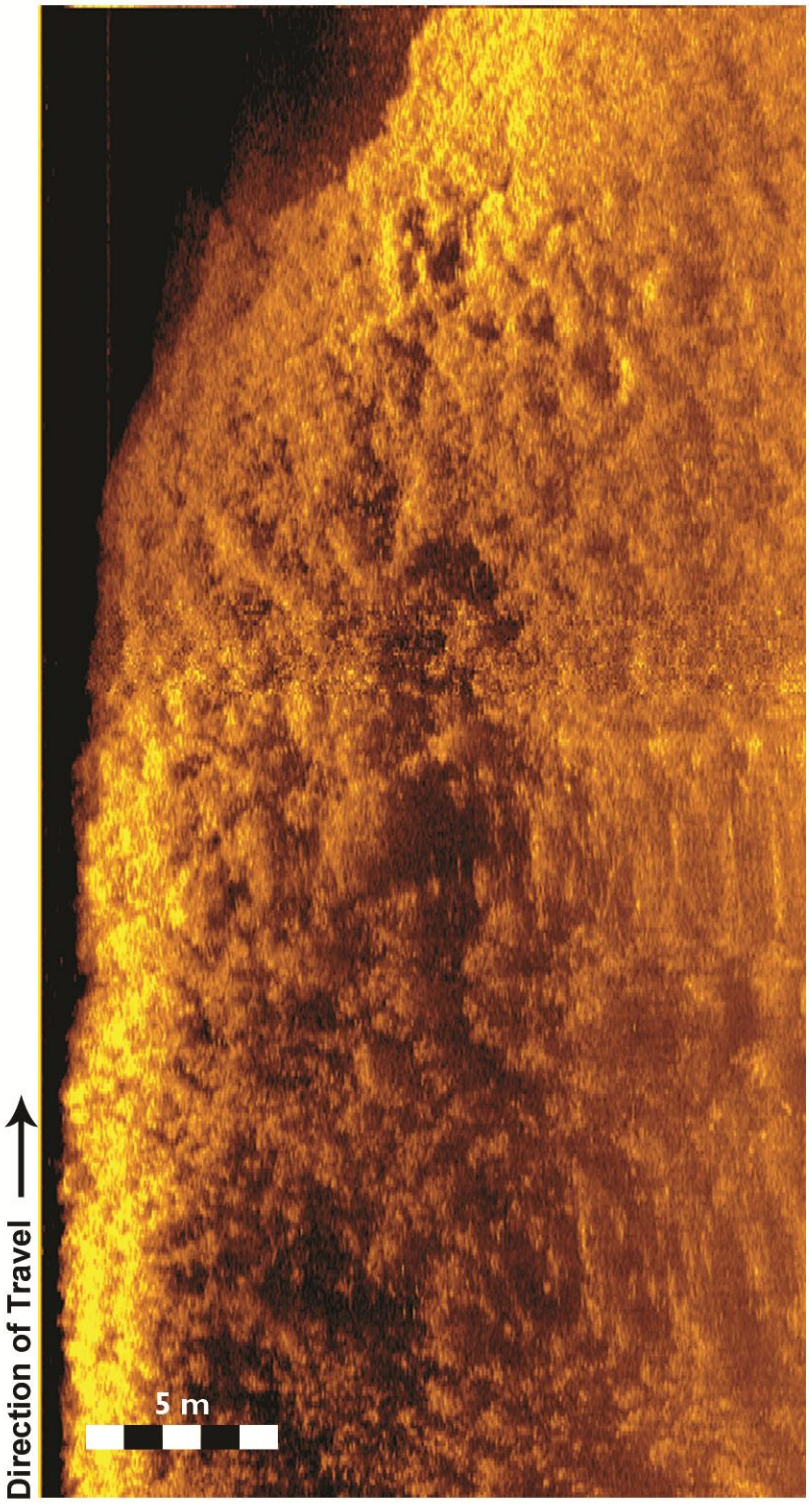

Figure 70: File 31Oct160, 1800 kHz, 20 m, acoustic signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

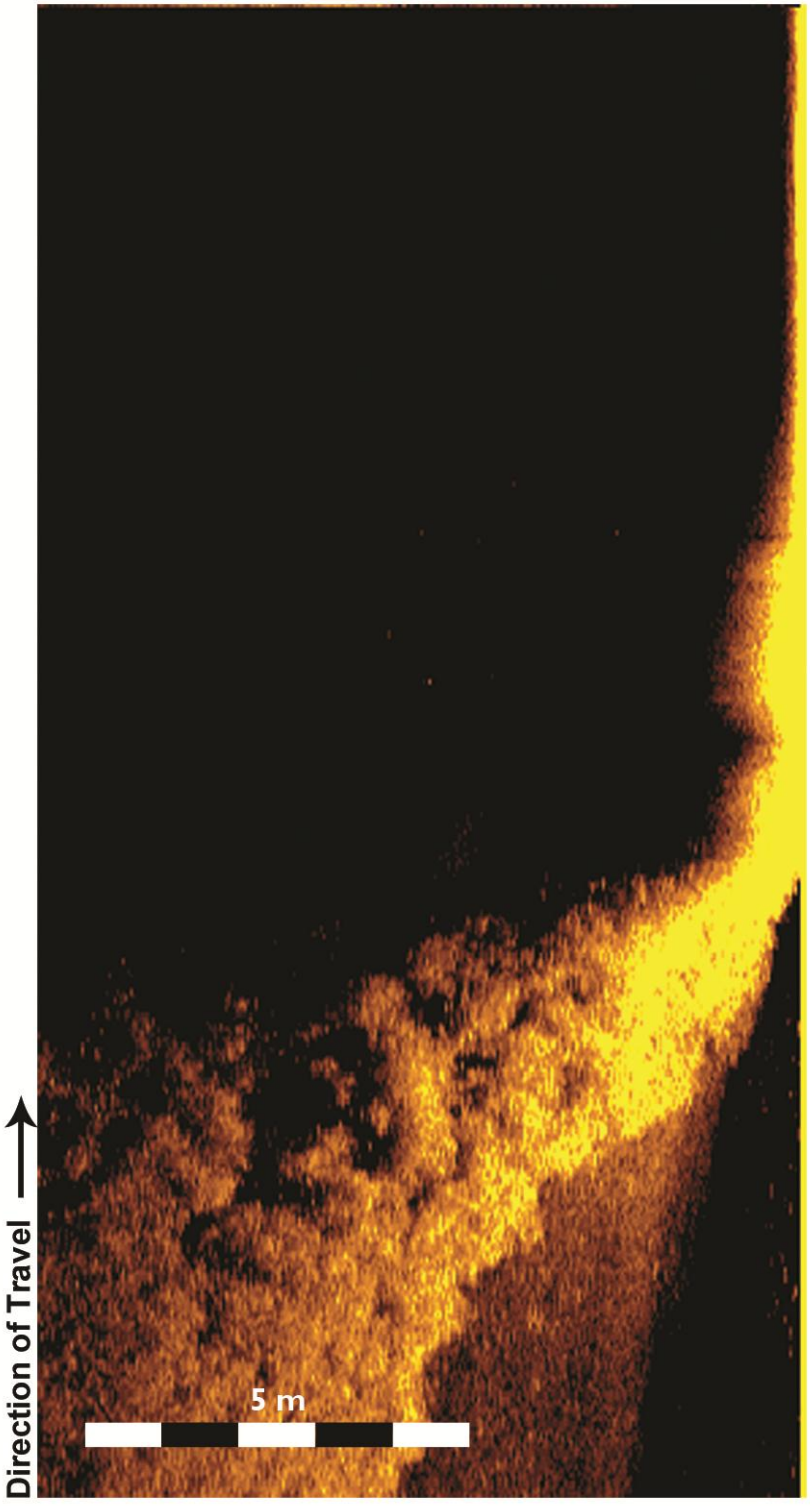

Figure 71: File 01Nov100, 900 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

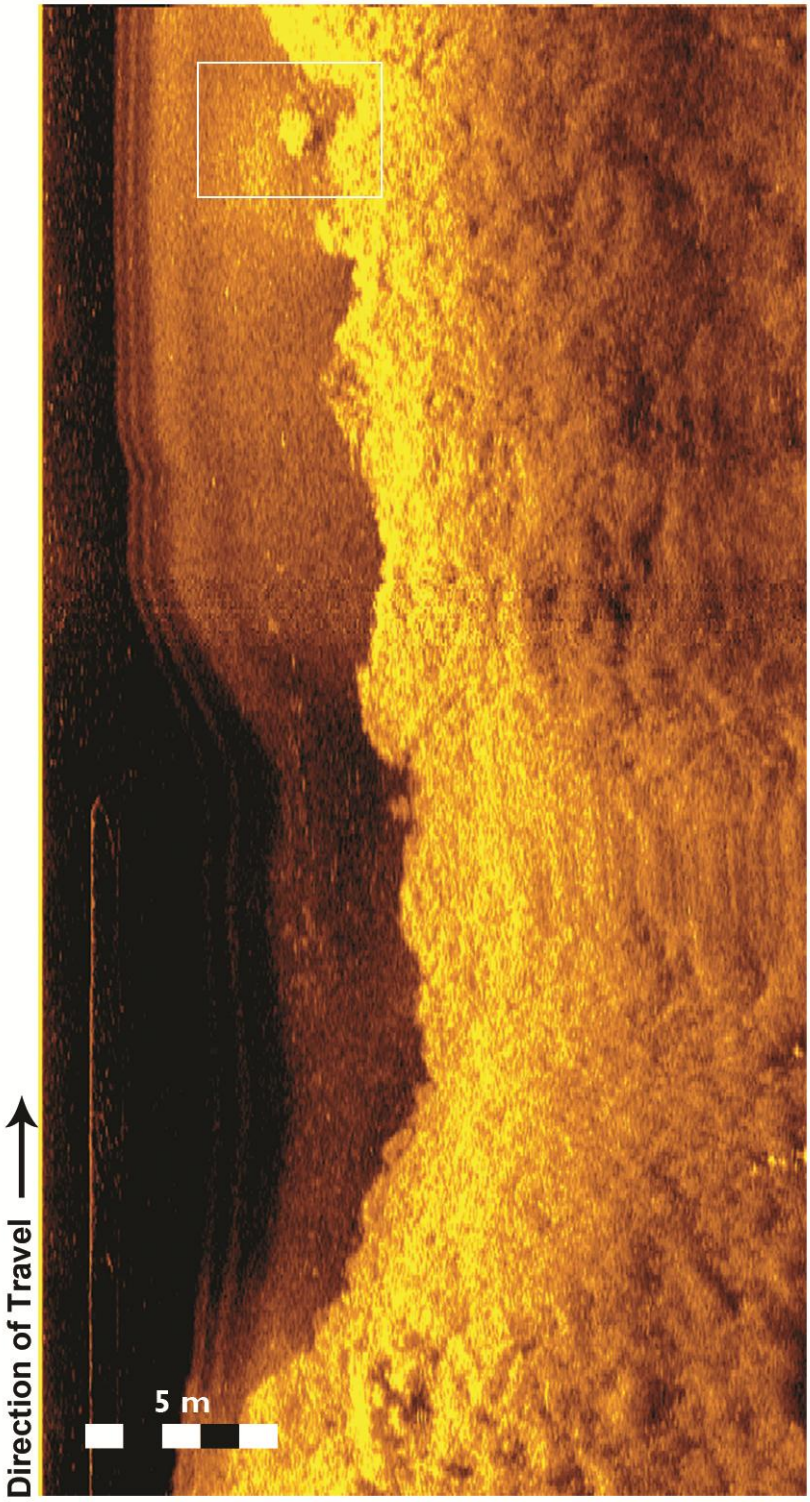

Figure 72: File 01Nov130, 900 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "good."

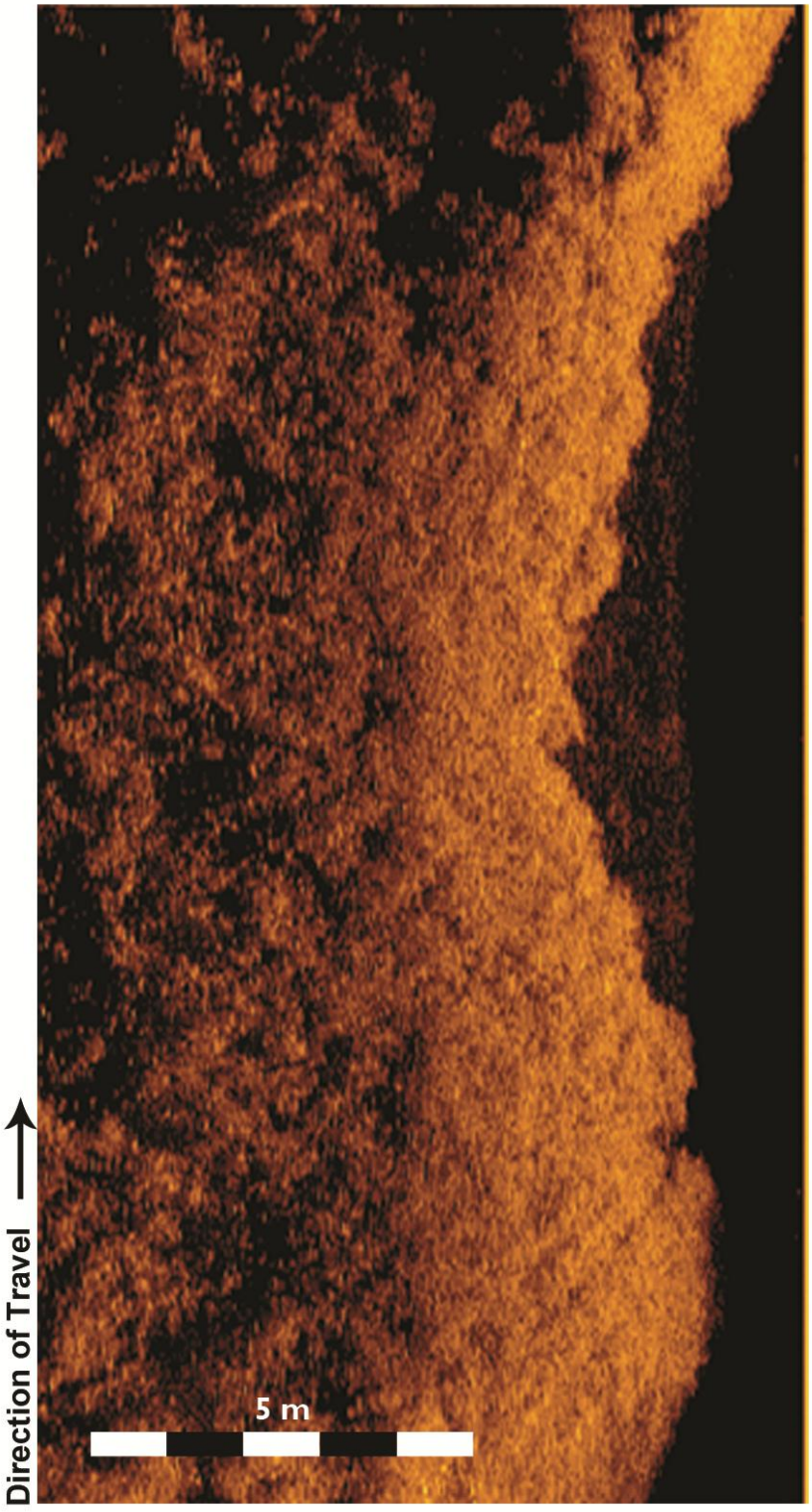

Figure 73: File 01Nov126, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

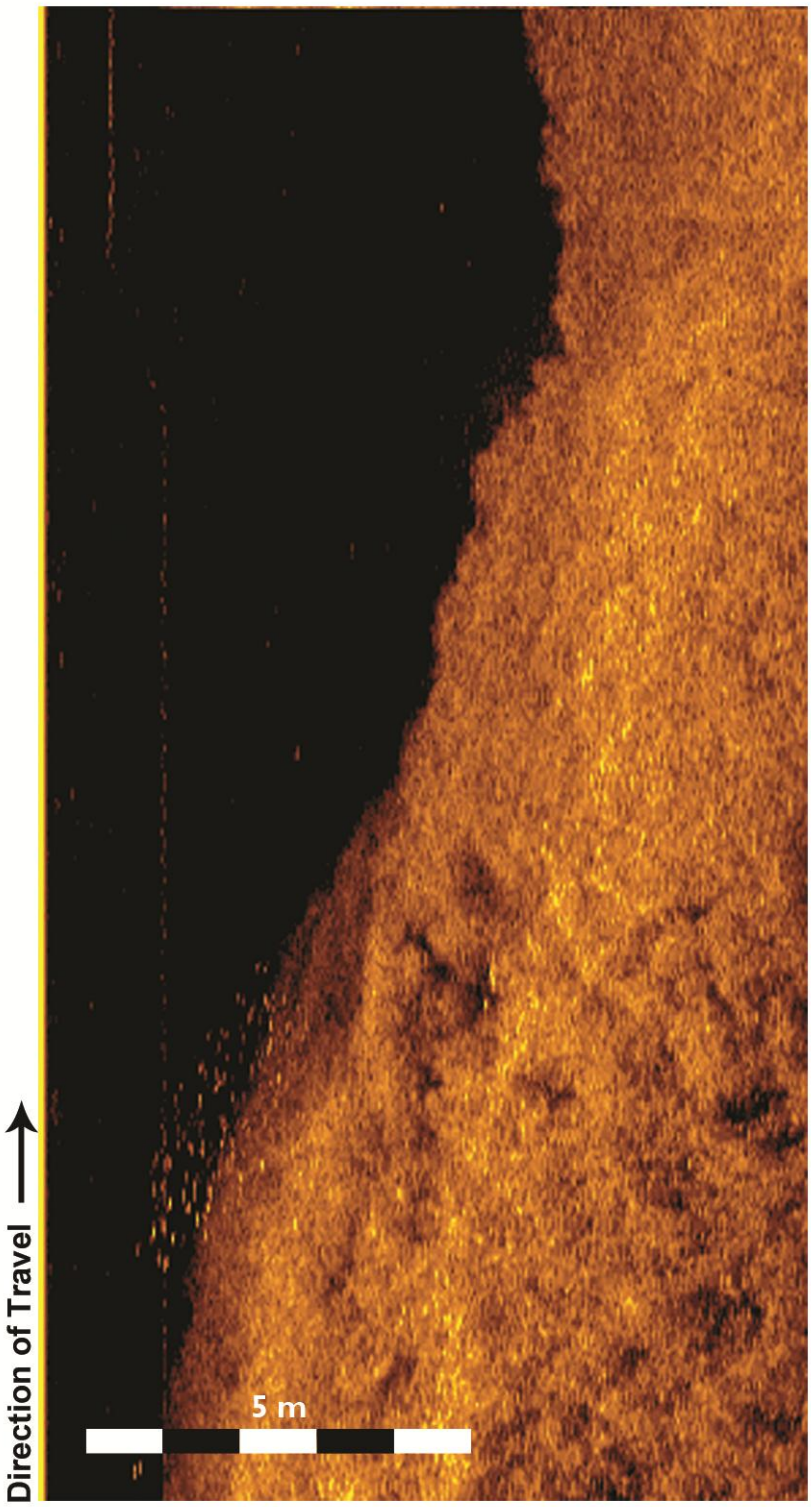

Figure 74: File 04Nov069, 900 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

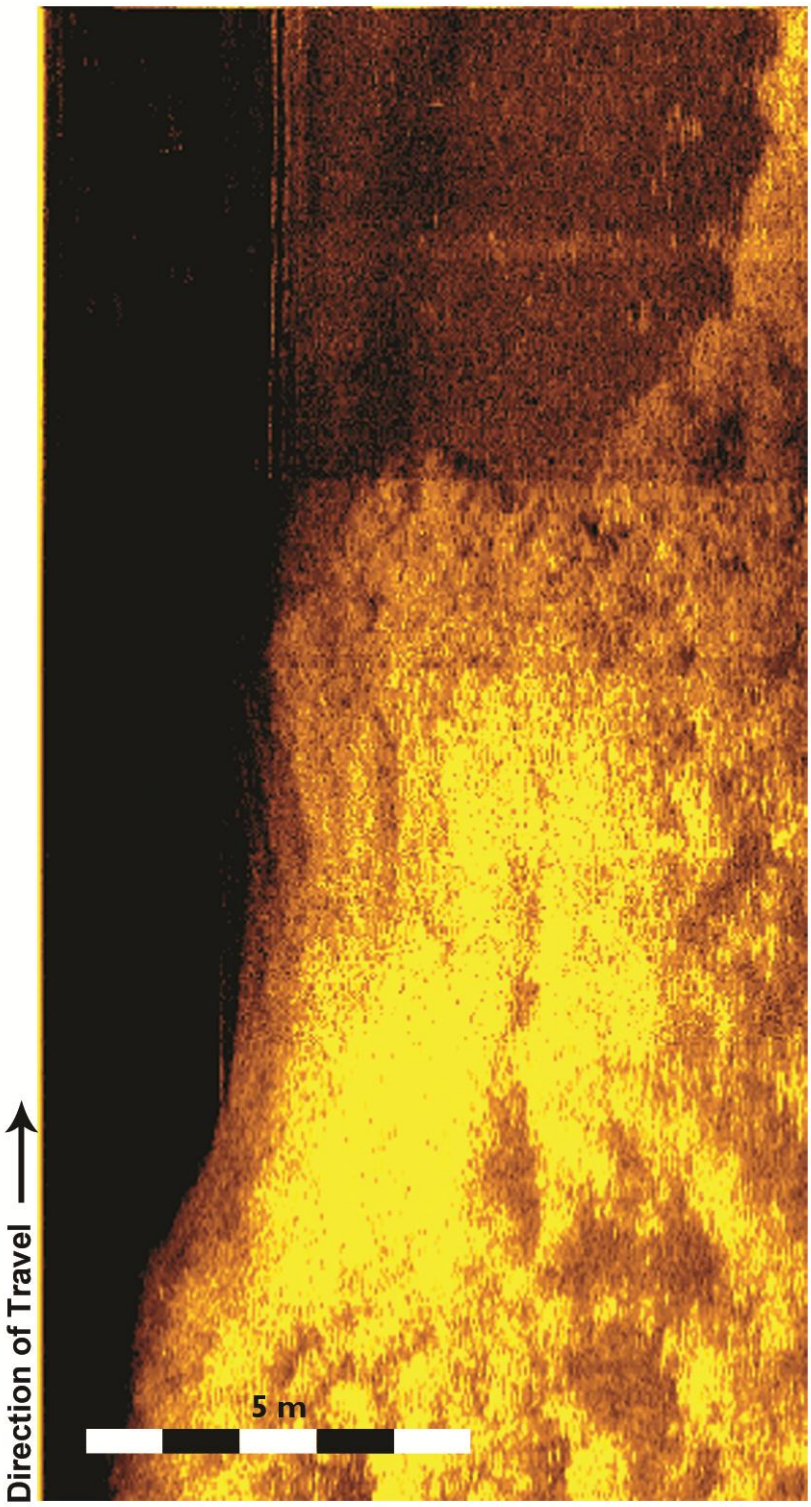

Figure 75: File 04Nov094, 1800 kHz, 10 m, signals transmitted out of the right side of the towfish. Pig carcass not detected and scored as "none."

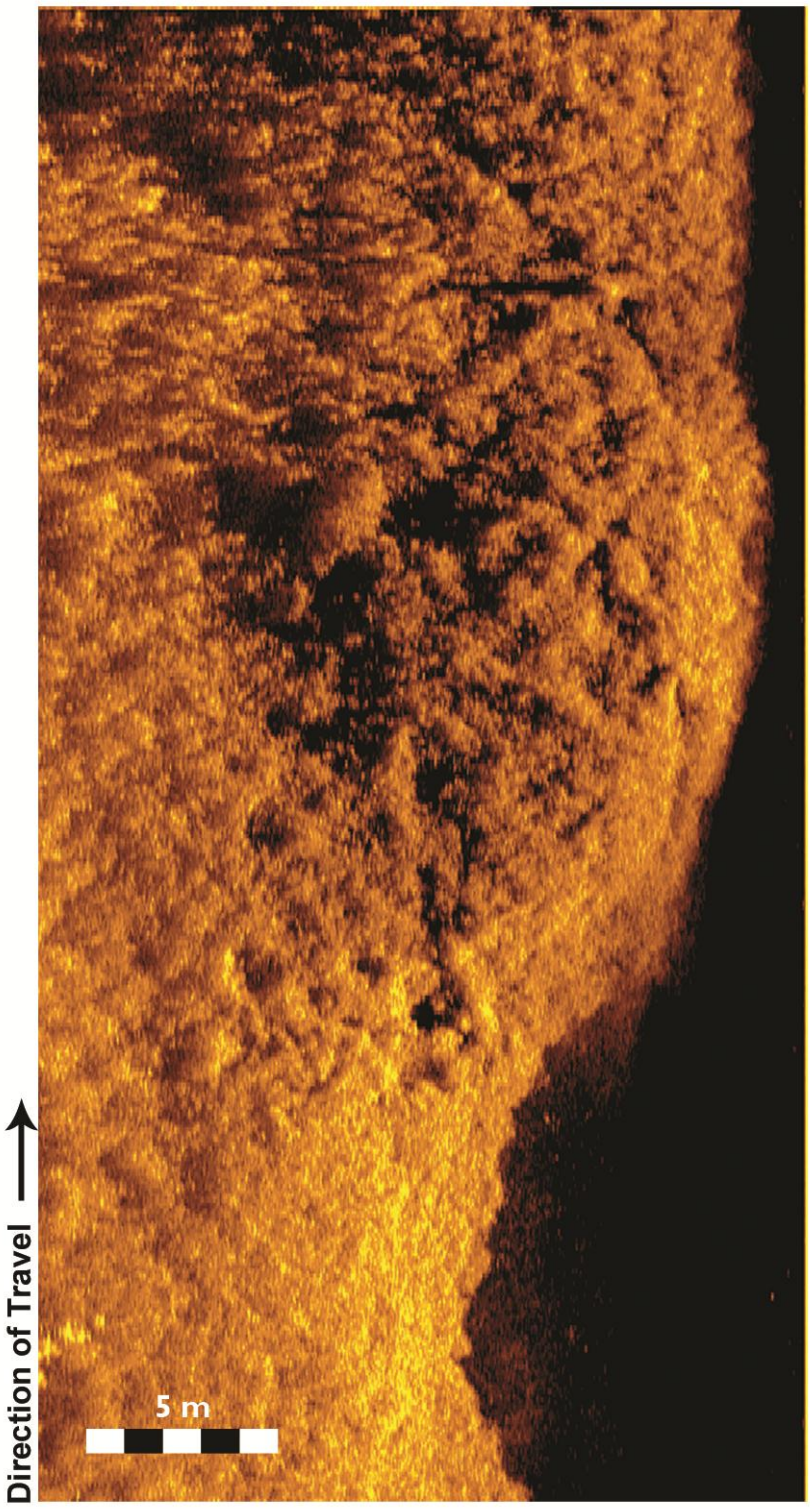

Figure 76: File 04Nov136, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

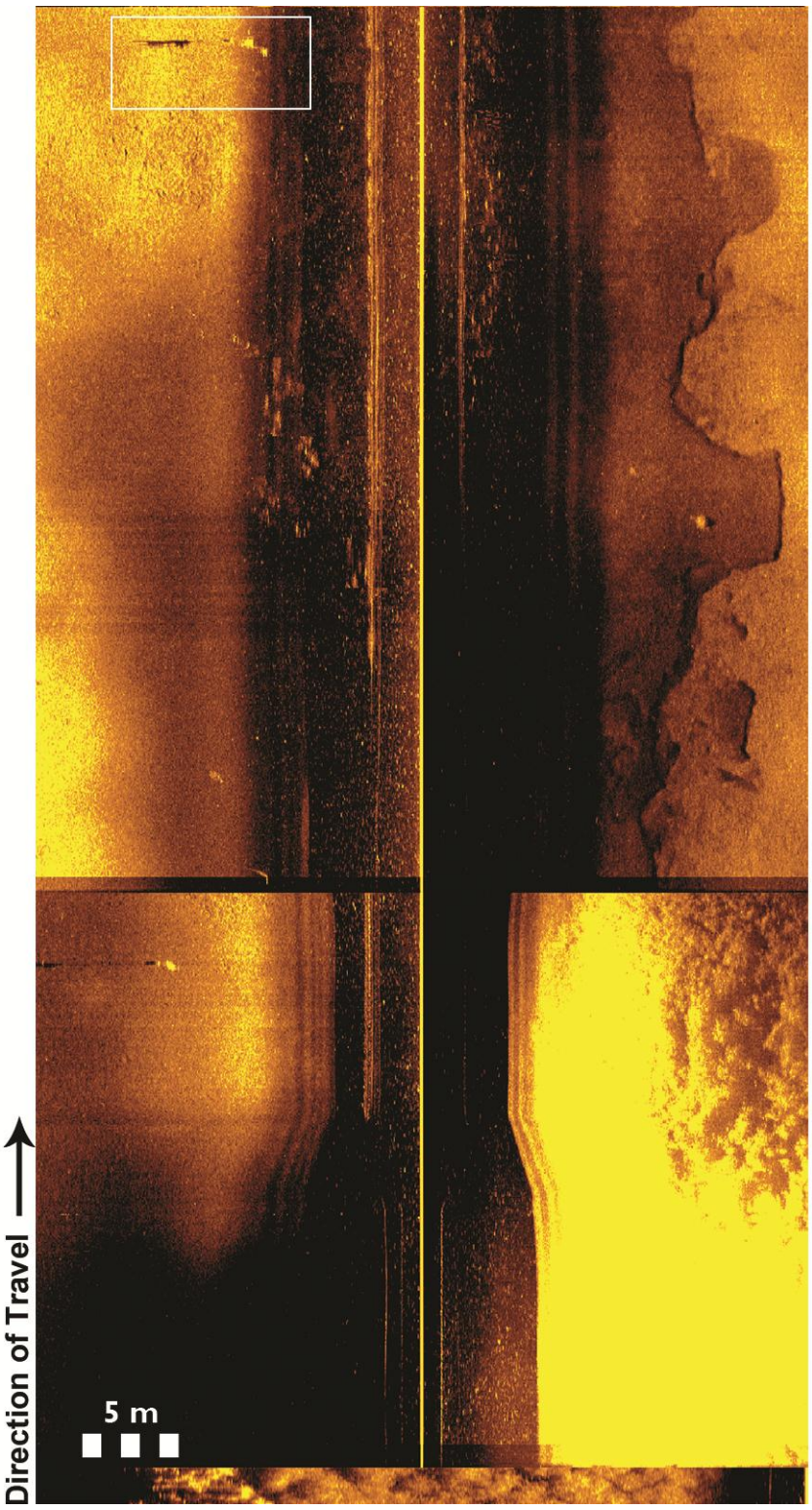

Figure 77: File 11Nov059, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [bottom] detected and scored as "good."

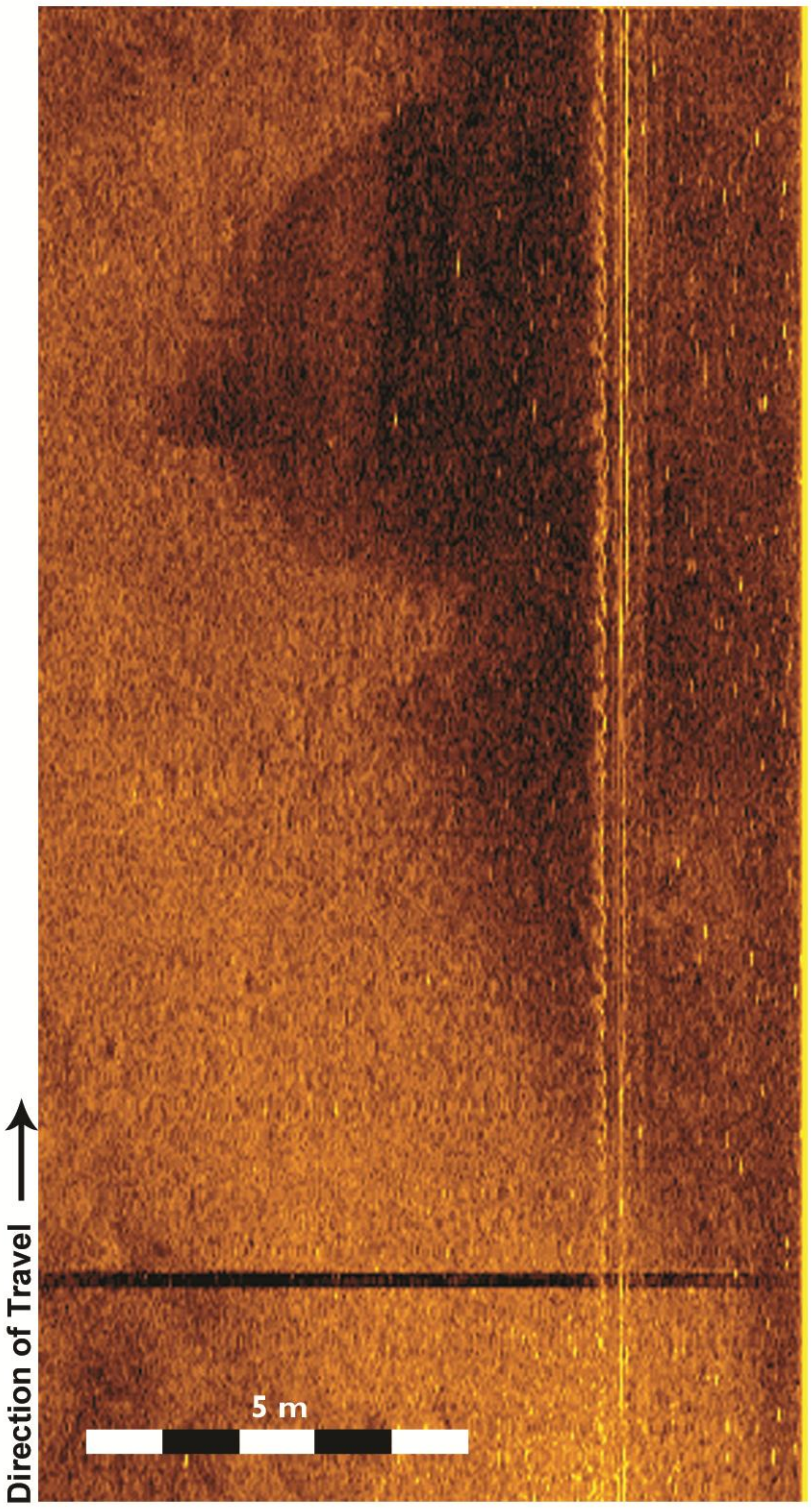

Figure 78: File 11Nov081, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass not detected and scored as "none."

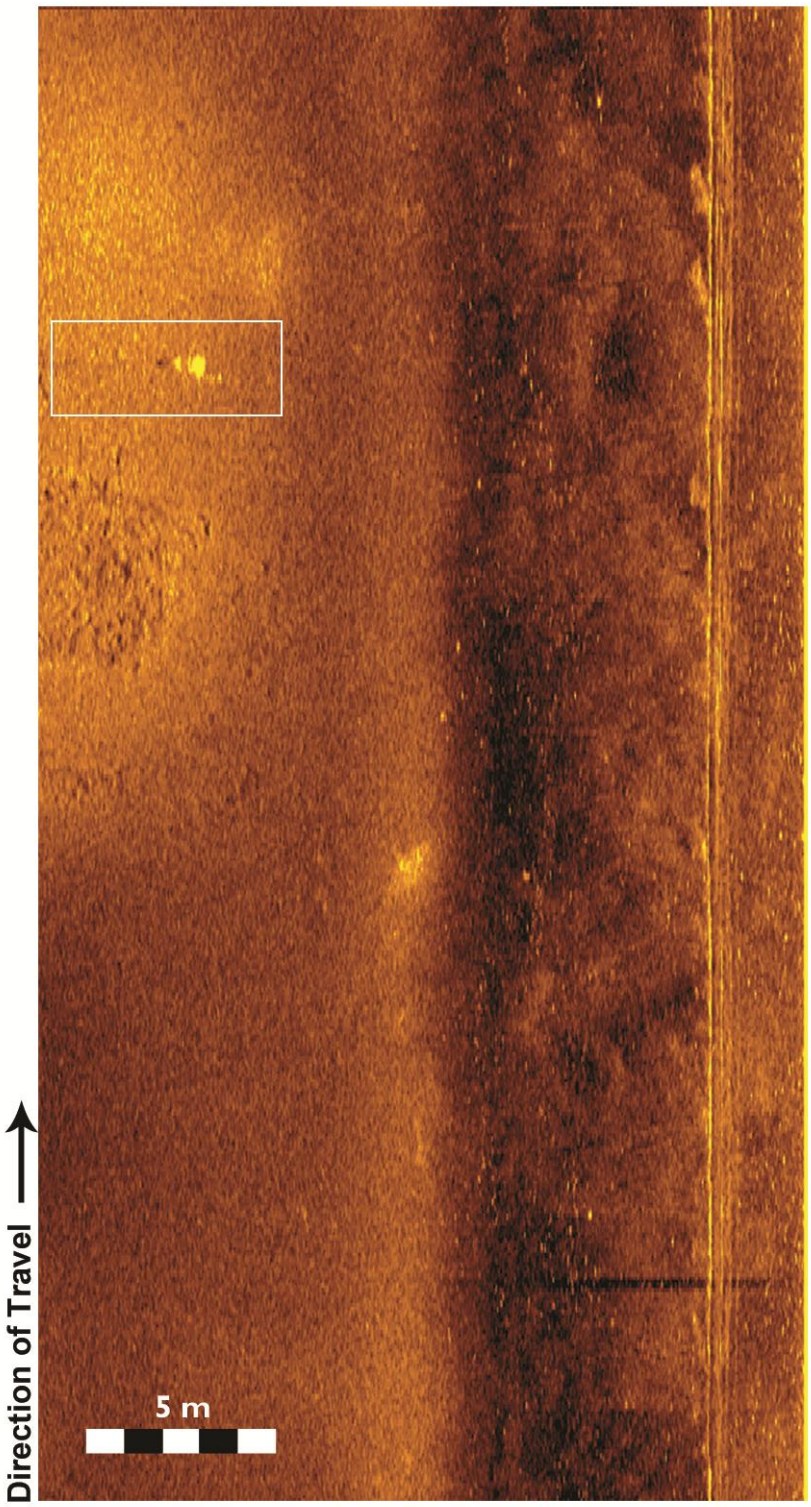

Figure 79: File 11Nov075, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

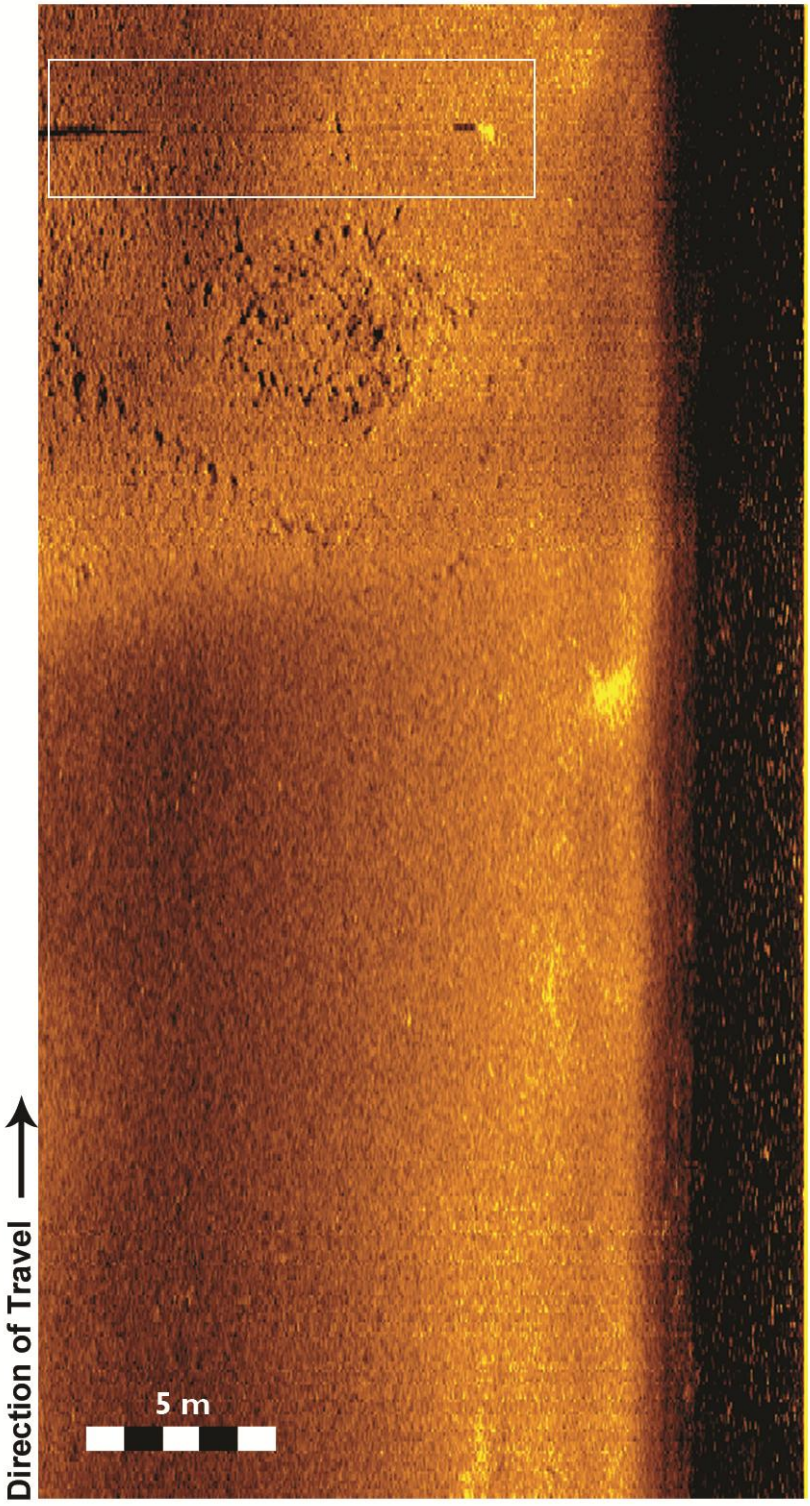

Figure 80: File 14Nov078, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

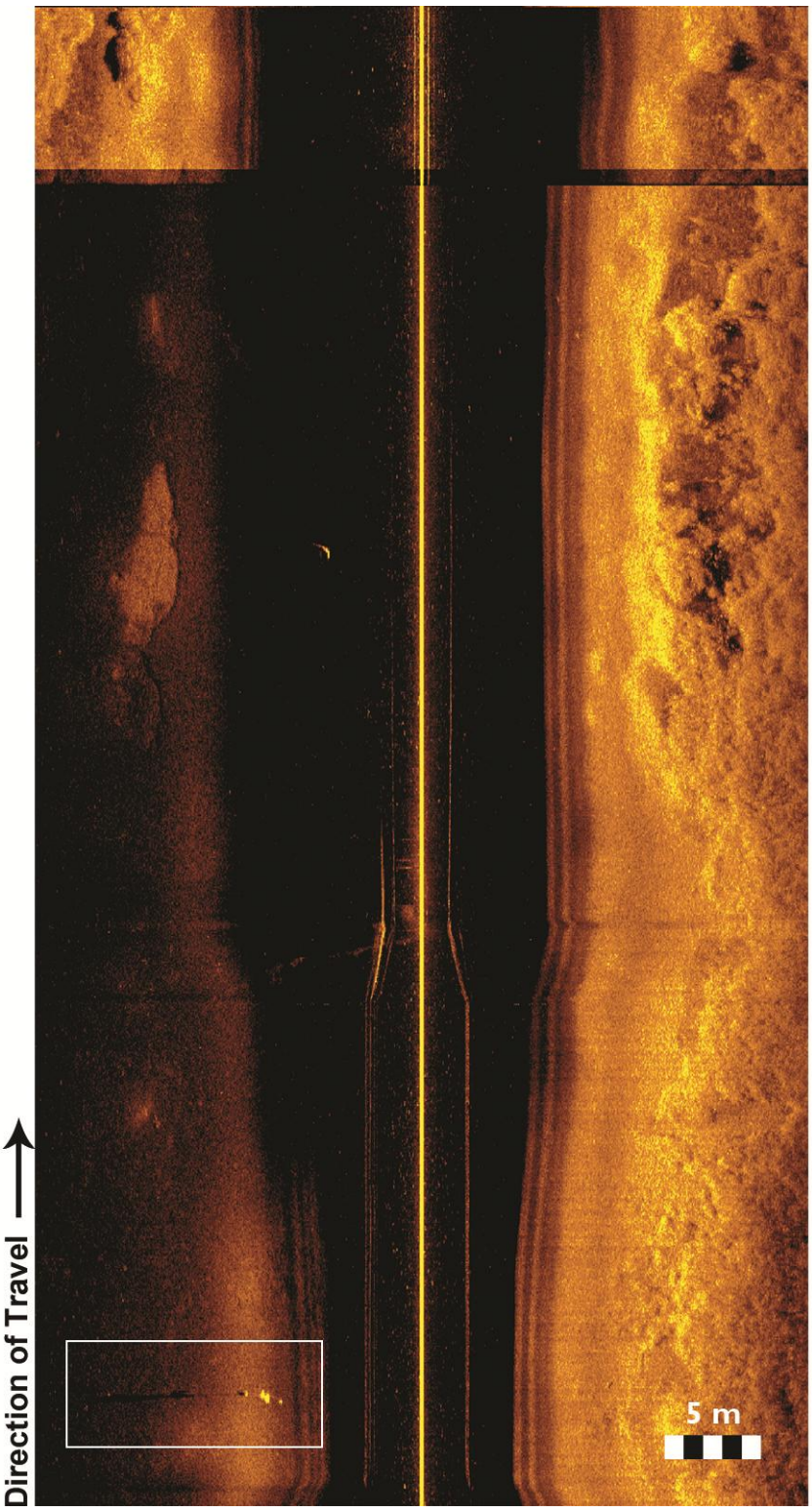

Figure 81: File 14Nov030, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

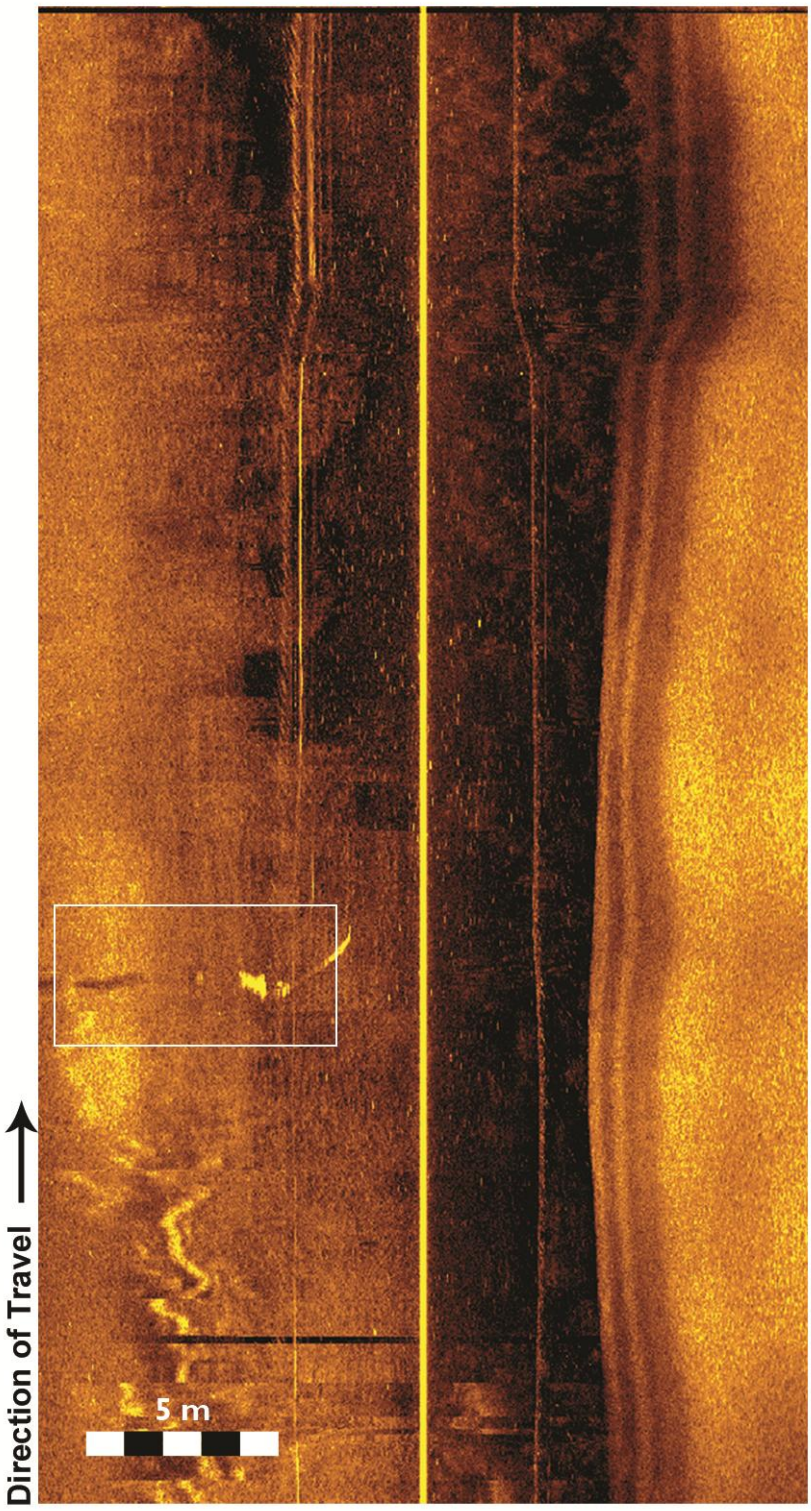

Figure 82: File 18Nov102, 900 kHz, 10 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "poor."

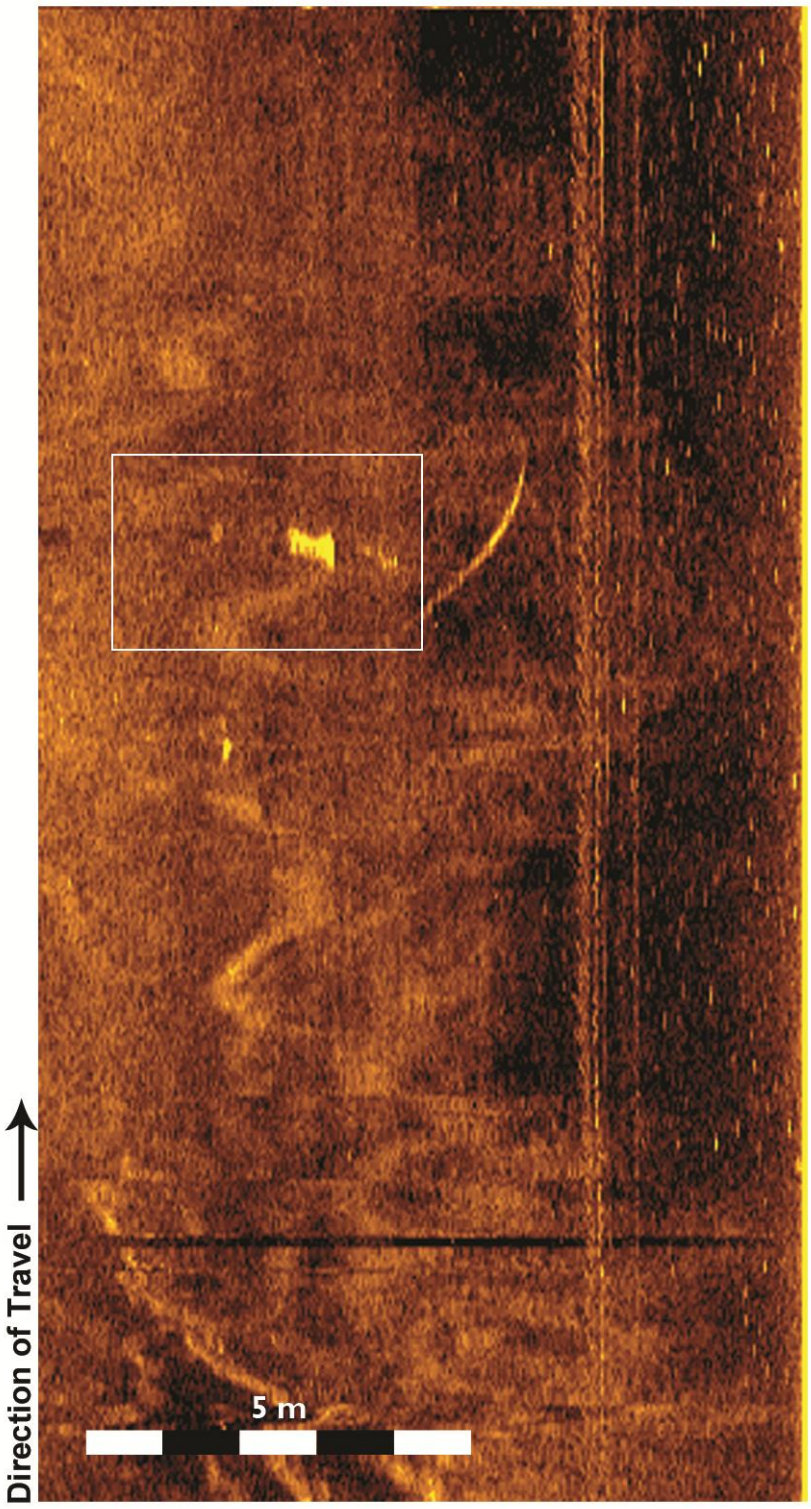

Figure 83: File 18Nov091, 1800 kHz, 10 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

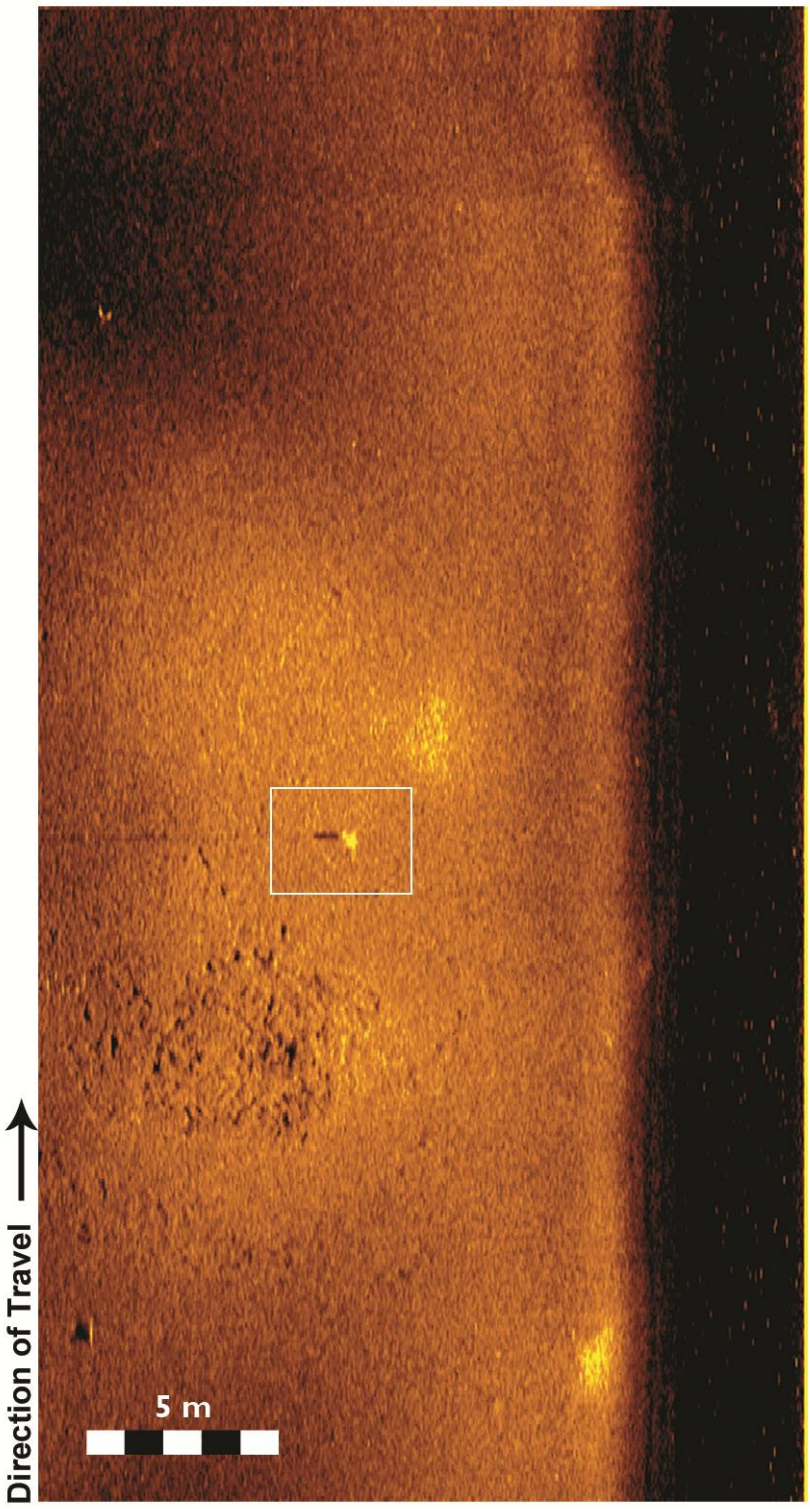

Figure 84: File 18Nov036, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

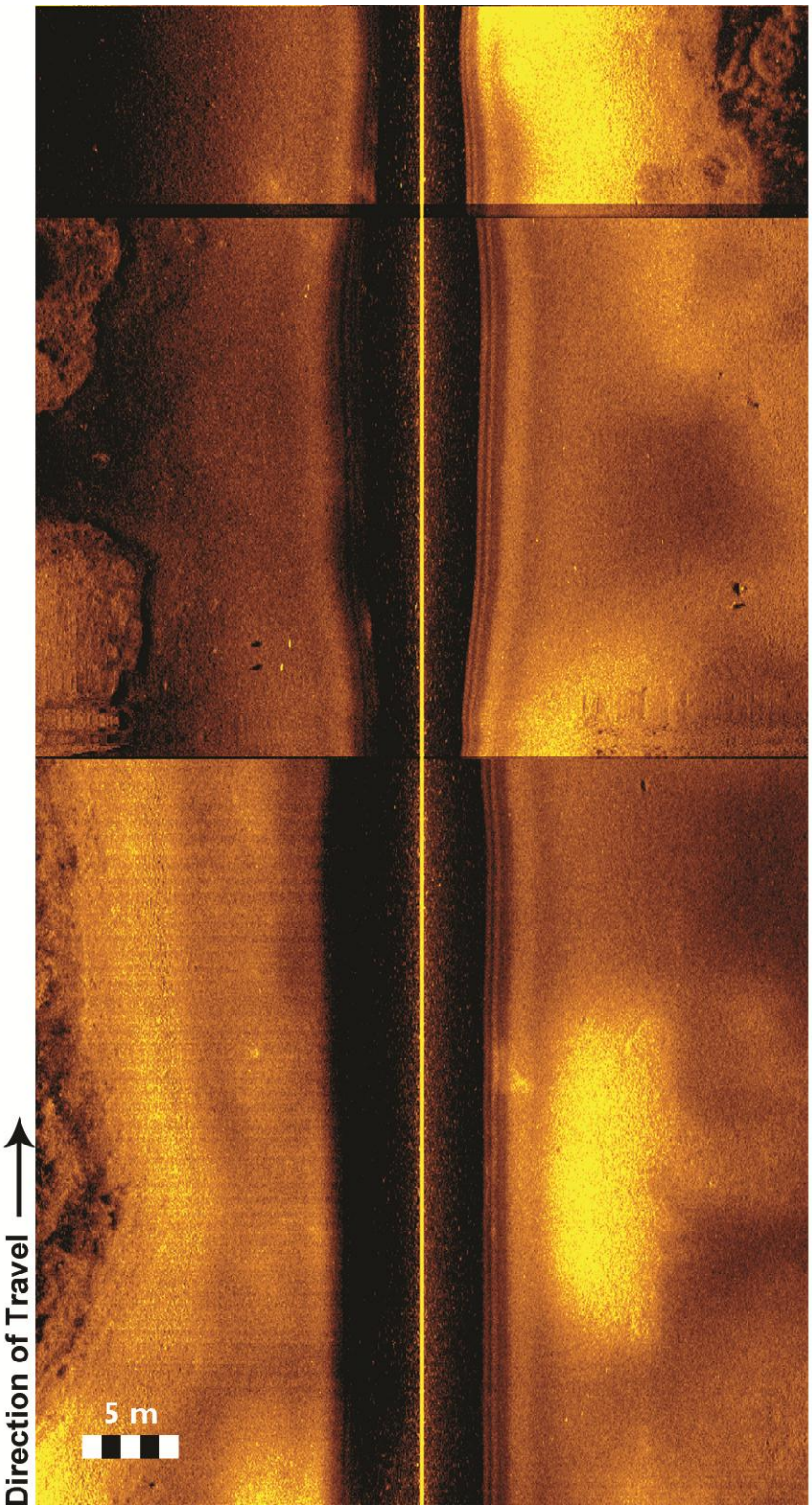

Figure 85: File 27Jan010, 900 kHz, 20 m, acoustic signals transmitted out of both sides of the towfish. Pig carcass not detected and scored as "none."

APPENDIX E: SONAR IMAGES FROM PIG 2A

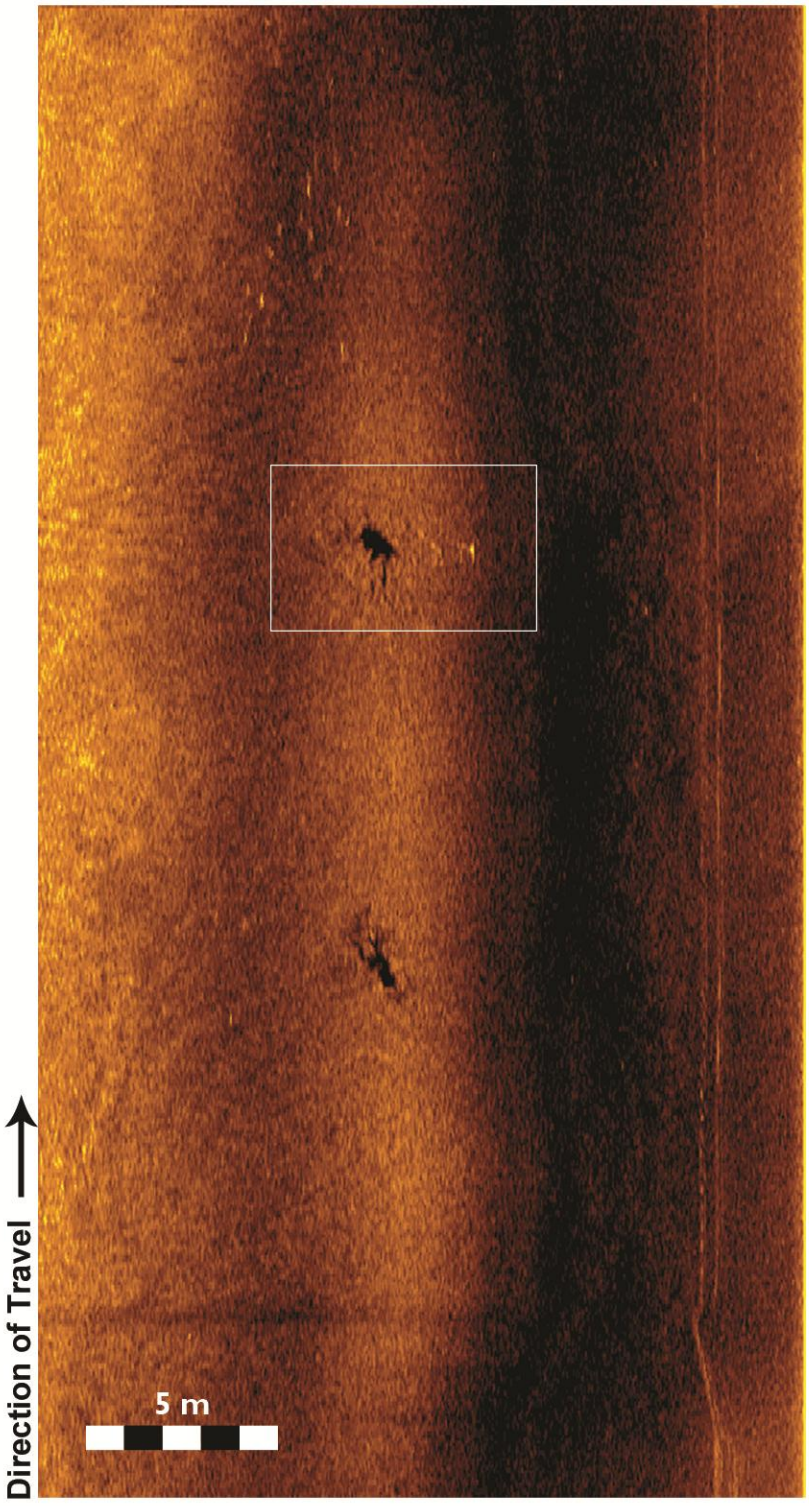

Figure 86: File 27Jan046, 900 kHz, 20 m, acoustic signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

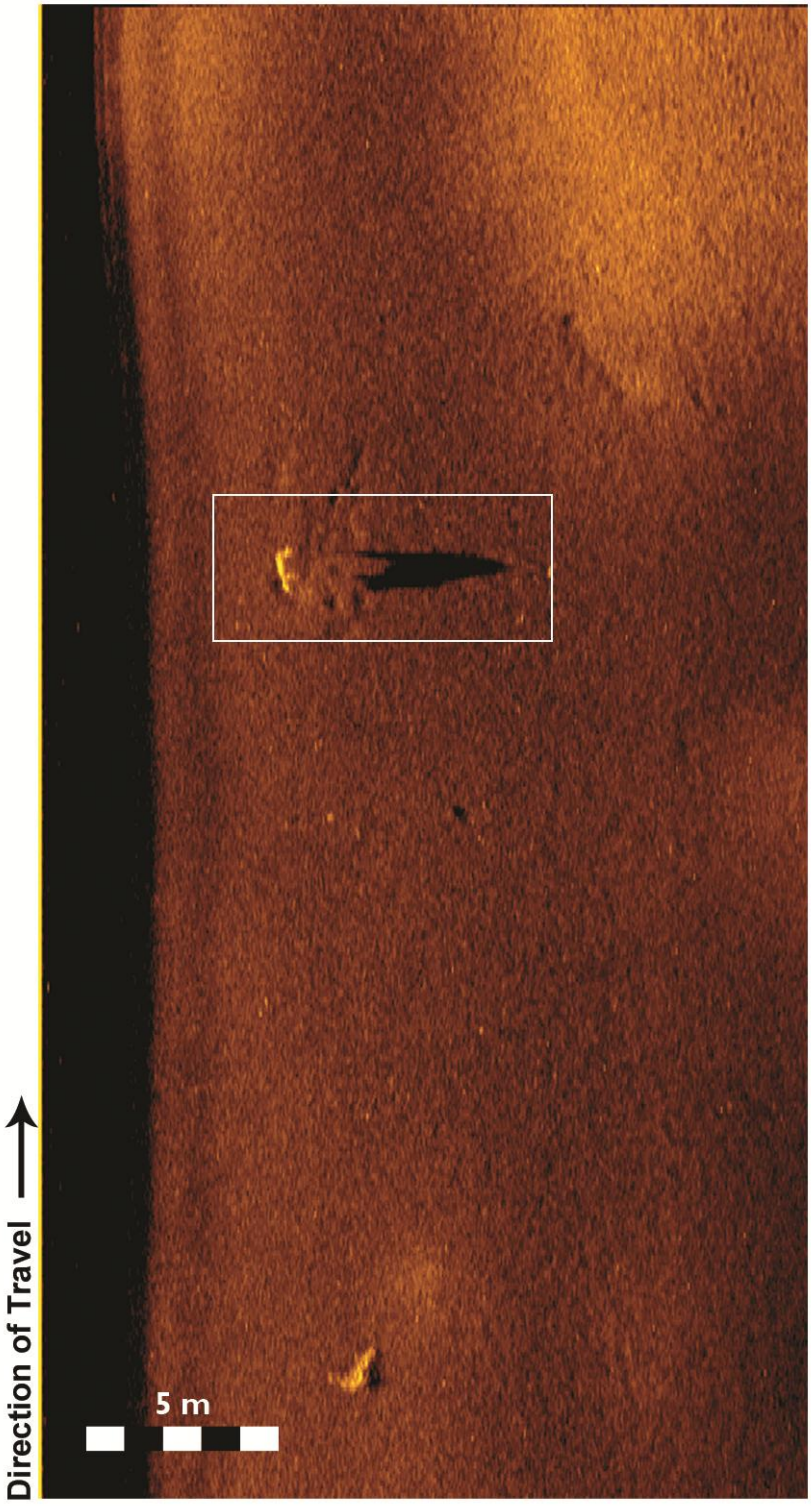

Figure 87: File 02Feb018; 900 kHz, 20 m, signal transmitted to the right of the towfish. Pig carcass detected and scored as "excellent."

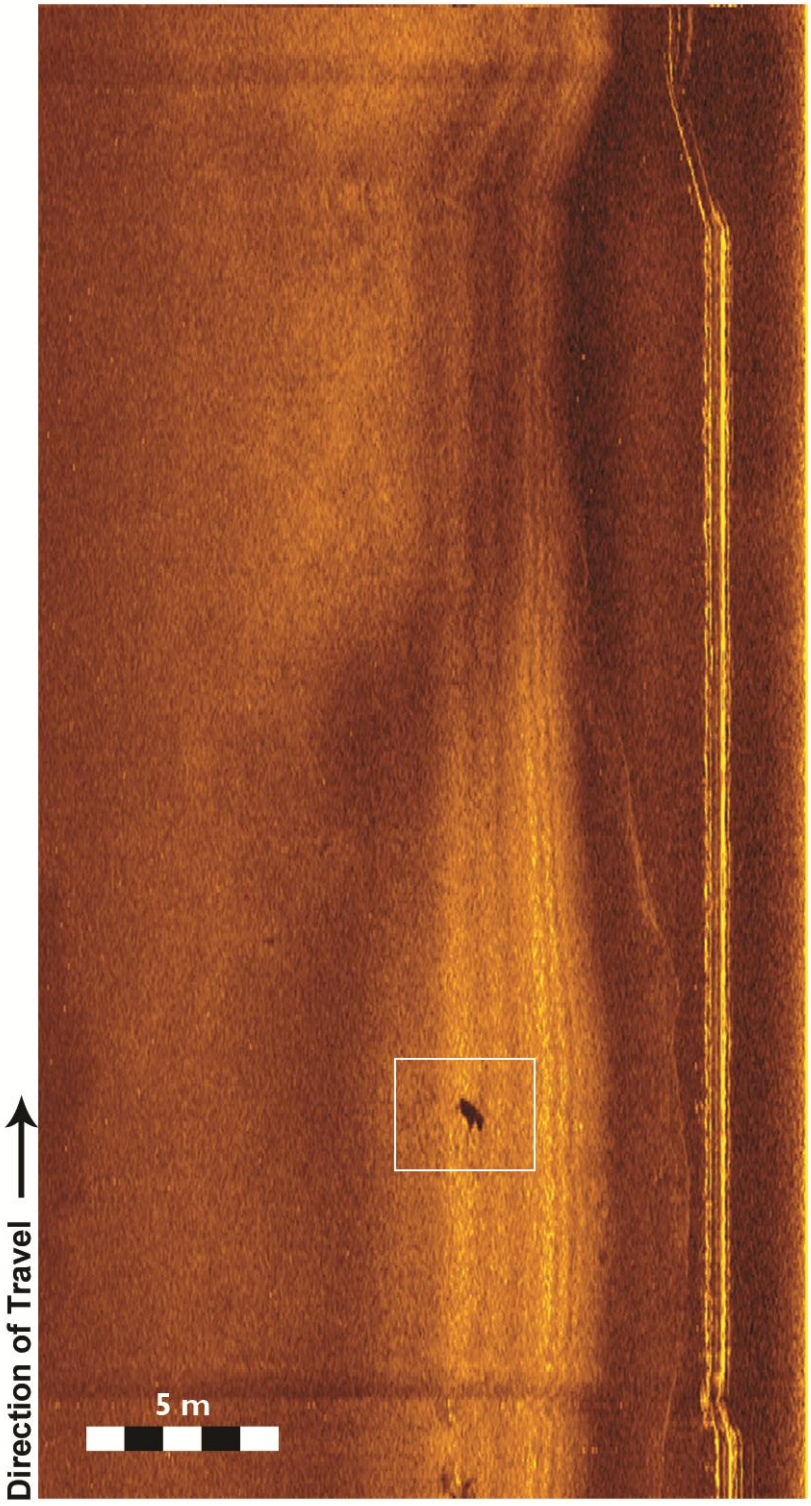

Figure 88: File 02Feb030; 1800 kHz, 20 m, signal transmitted to the right of the towfish. Pig carcass detected and scored as "excellent."

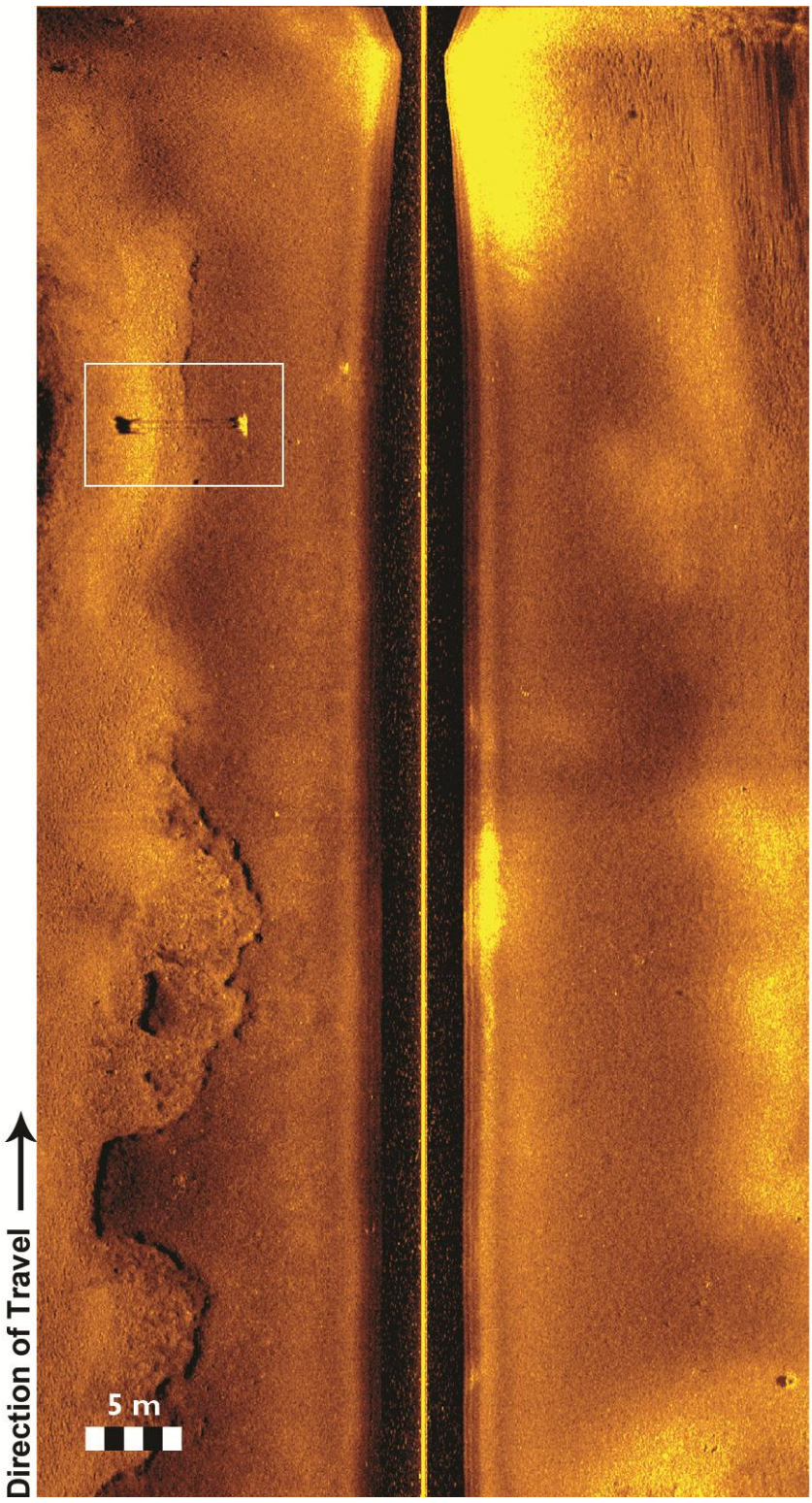

Figure 89: File 07Feb263, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "excellent."

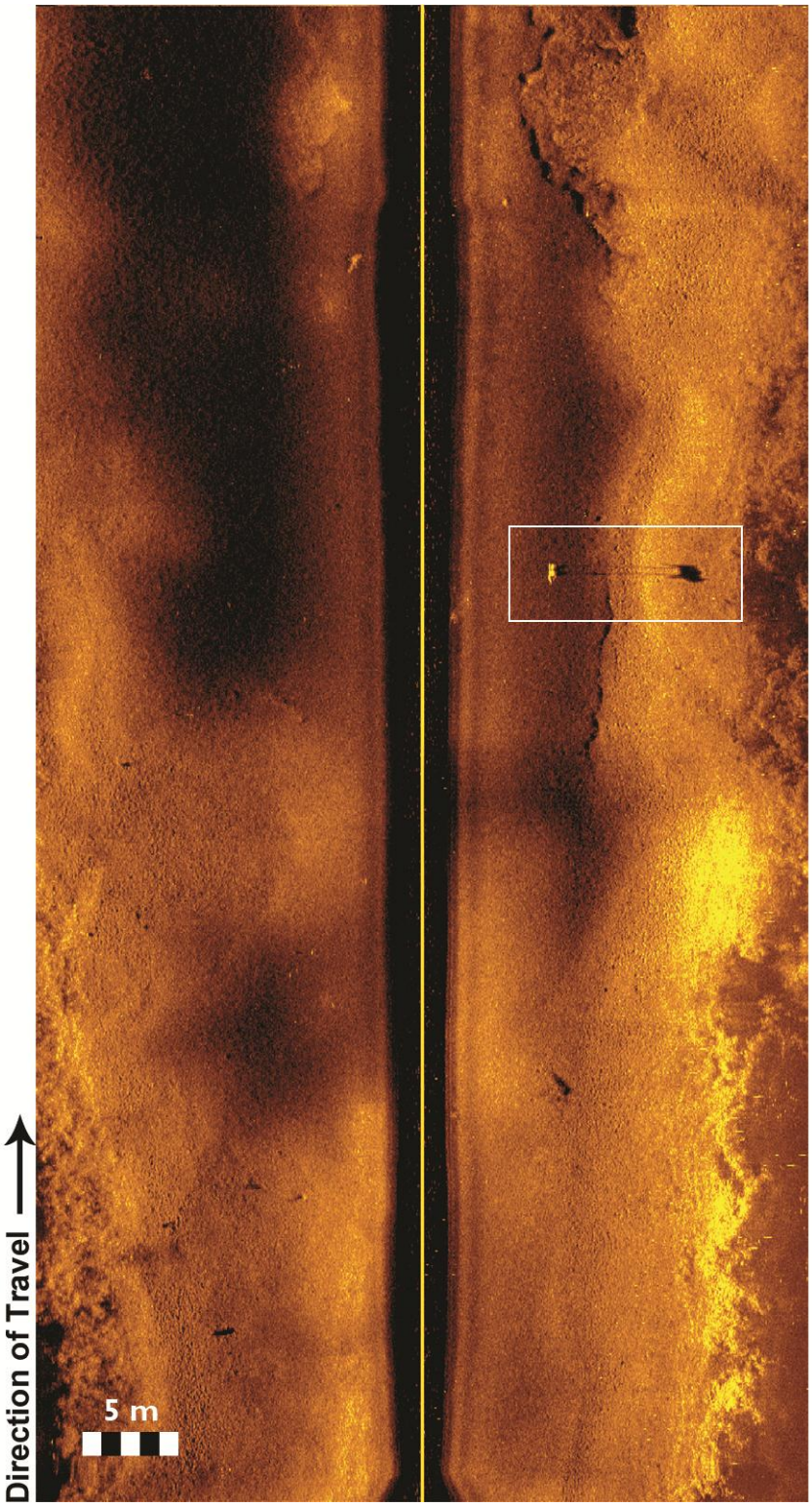

Figure 90: File 07Feb273, 1800 kHz, 20 m, signals transmitted out of both sides. Pig carcass detected and scored as "excellent."

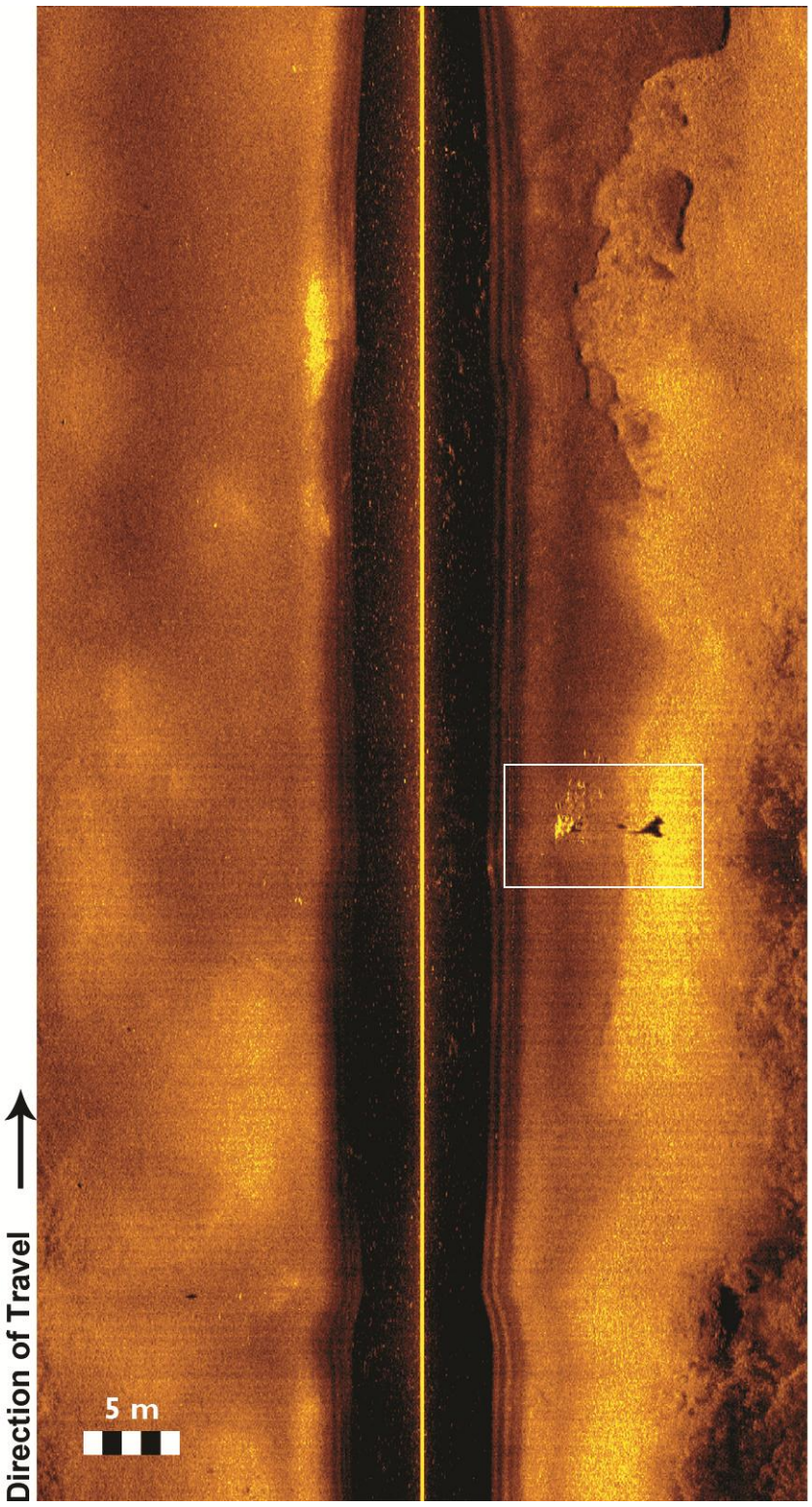

Figure 91: File 16Feb005, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

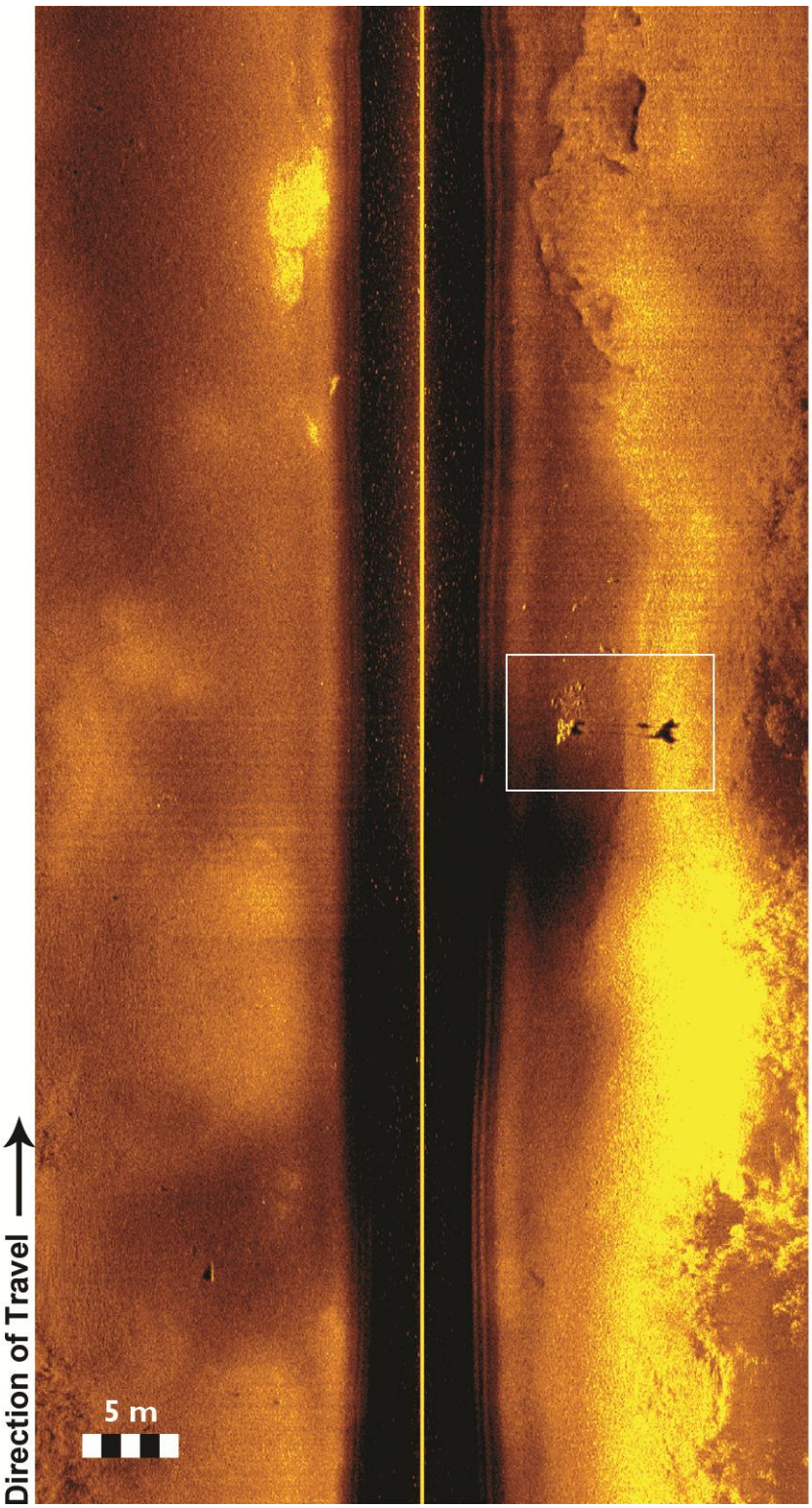

Figure 92: File 16Feb012, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

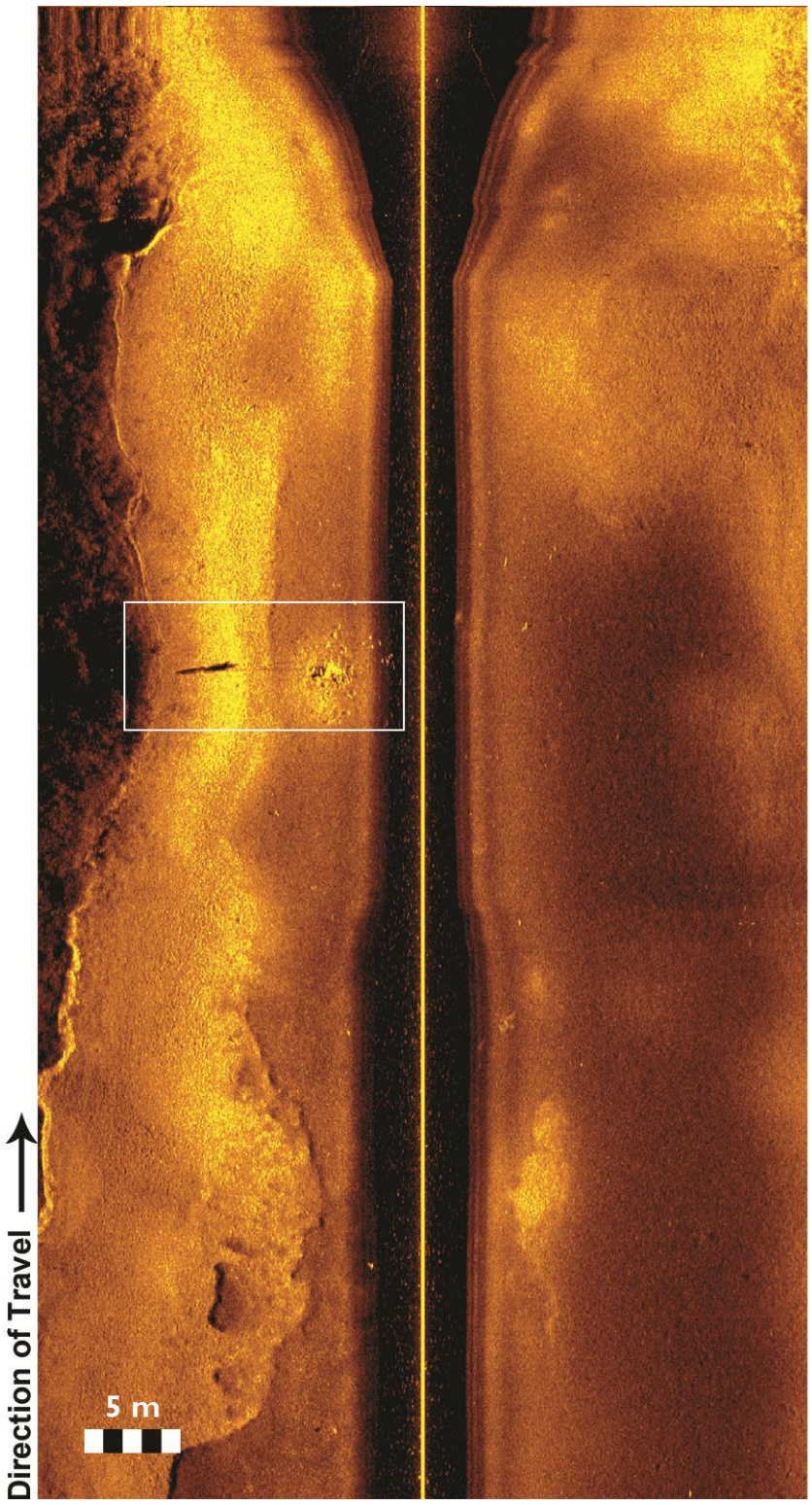

Figure 93: File 28Feb009, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

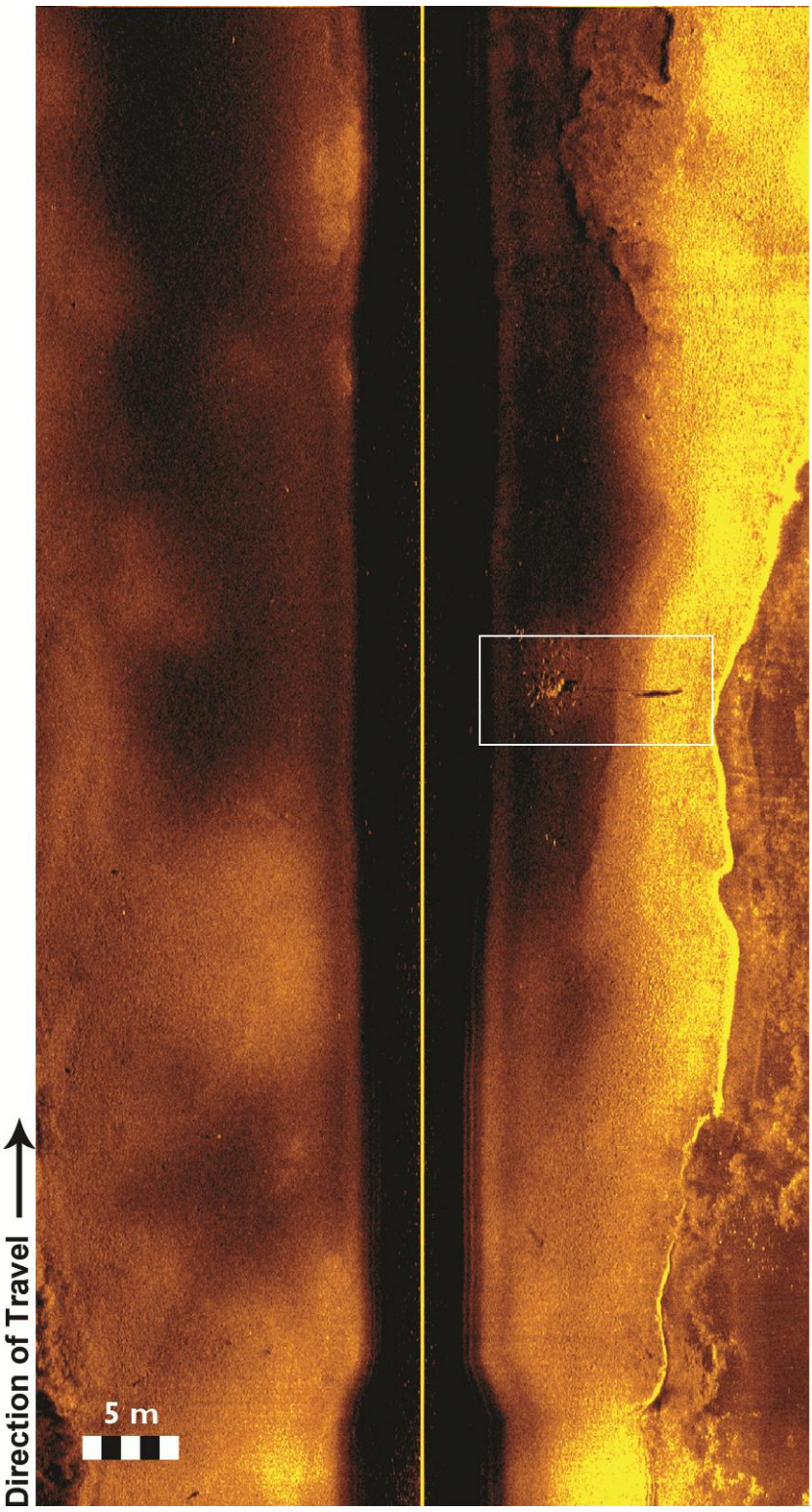

Figure 94: File 28Feb011, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

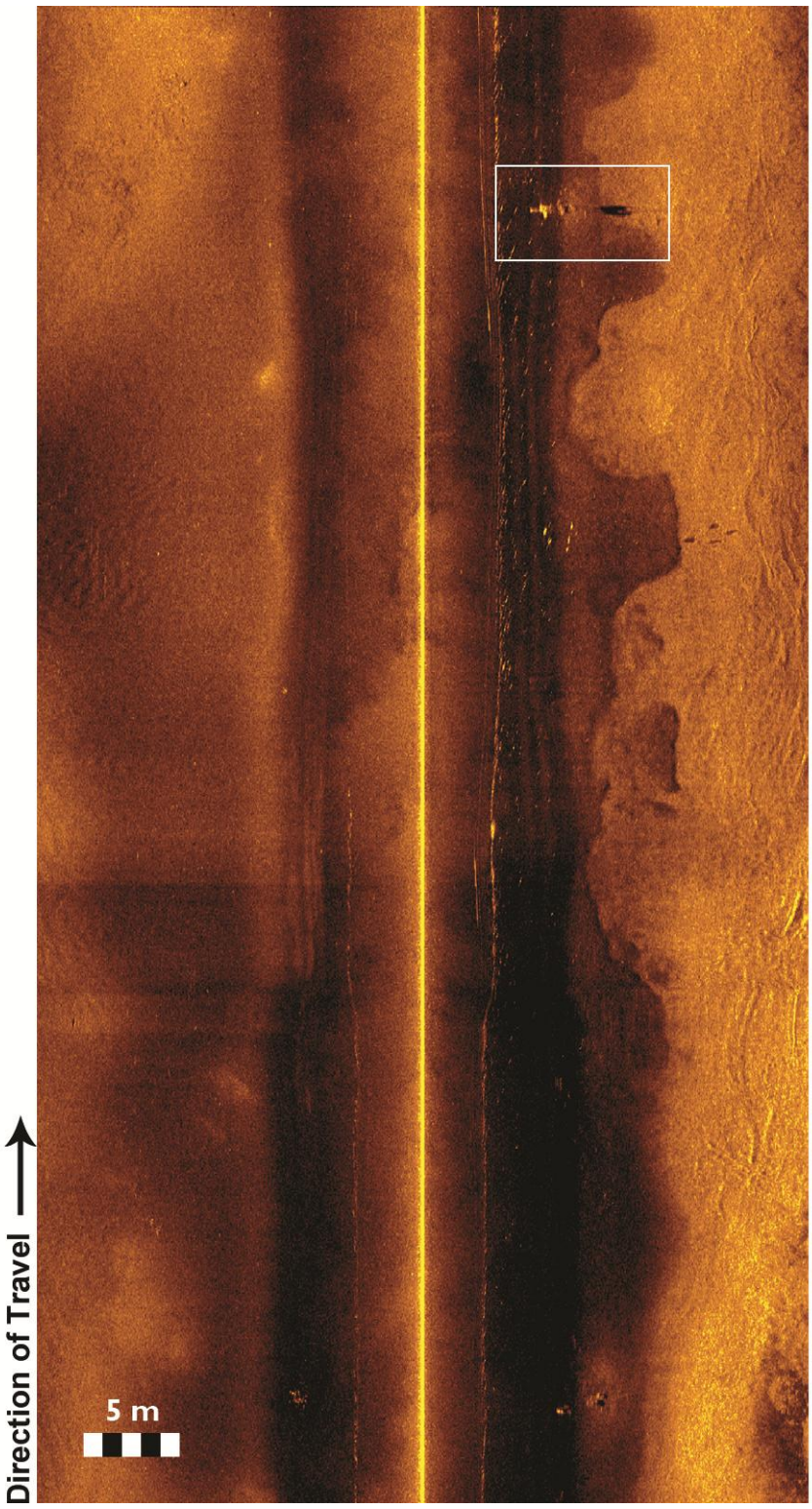

Figure 95: File 06Mar012, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

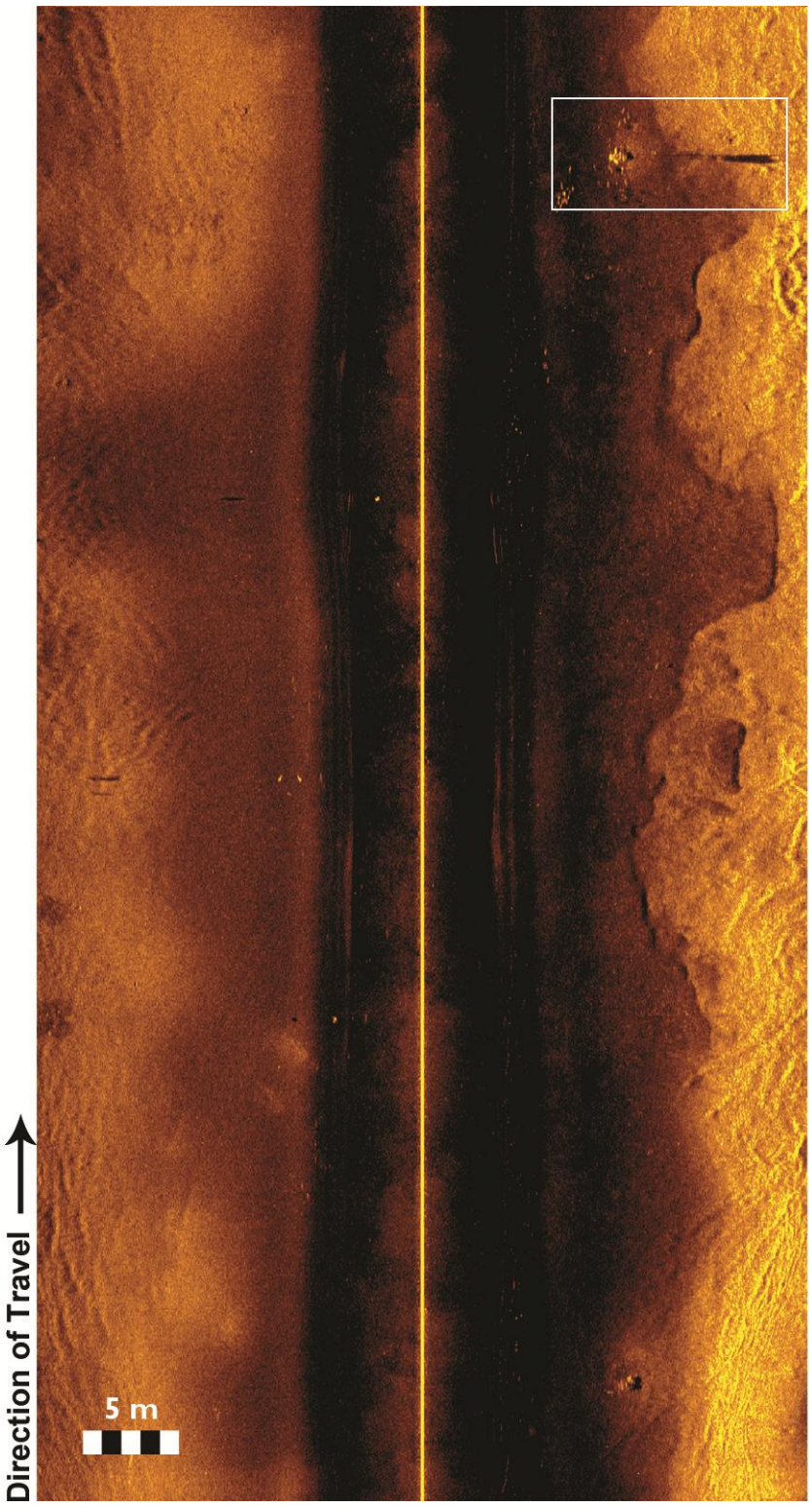

Figure 96: File 06Mar021, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

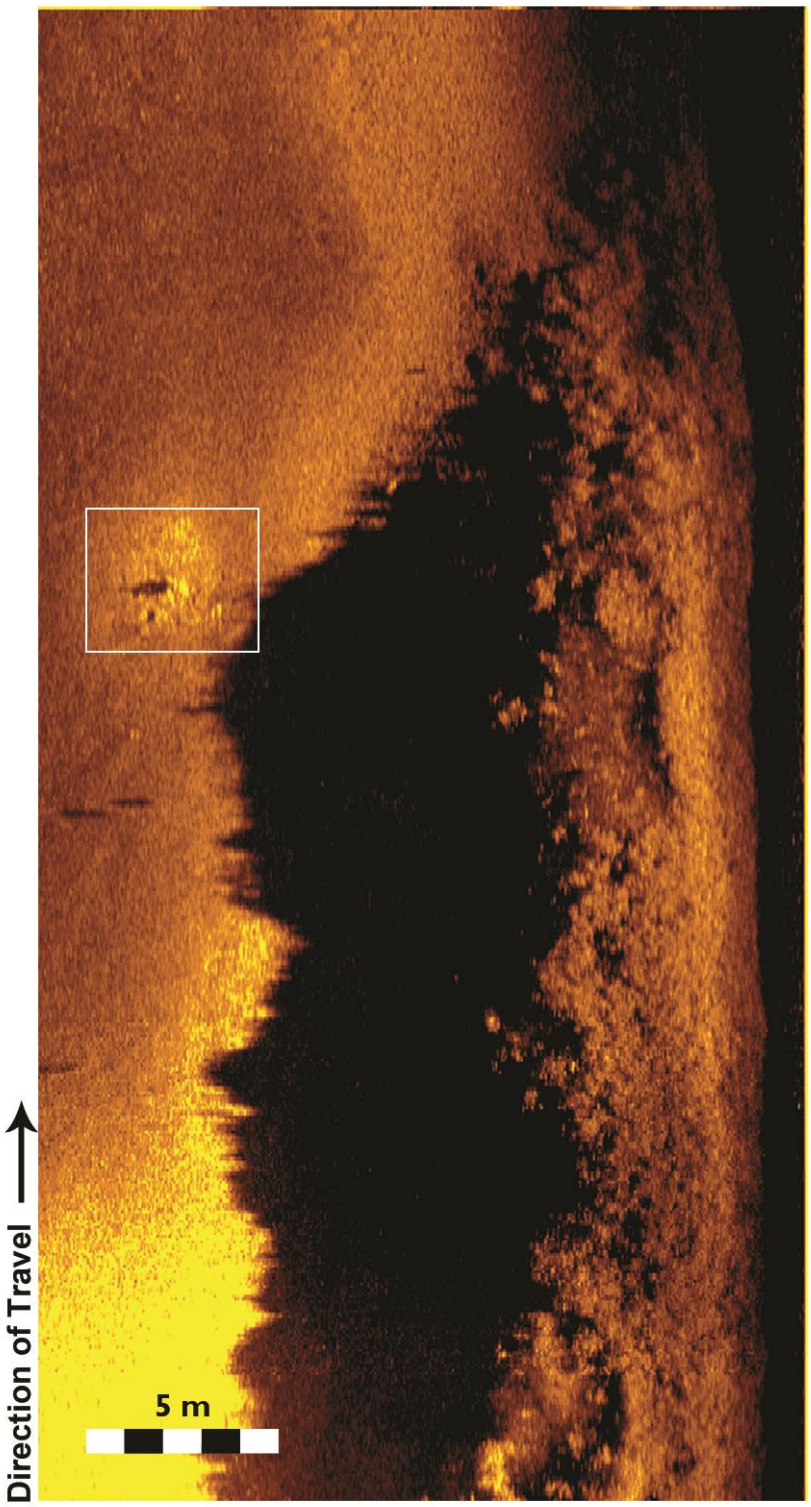

Figure 97: File19Mar014, 900 kHz, 20 m, signals transmitted to the left of the towfish. Pig carcass detected and scored as "poor."

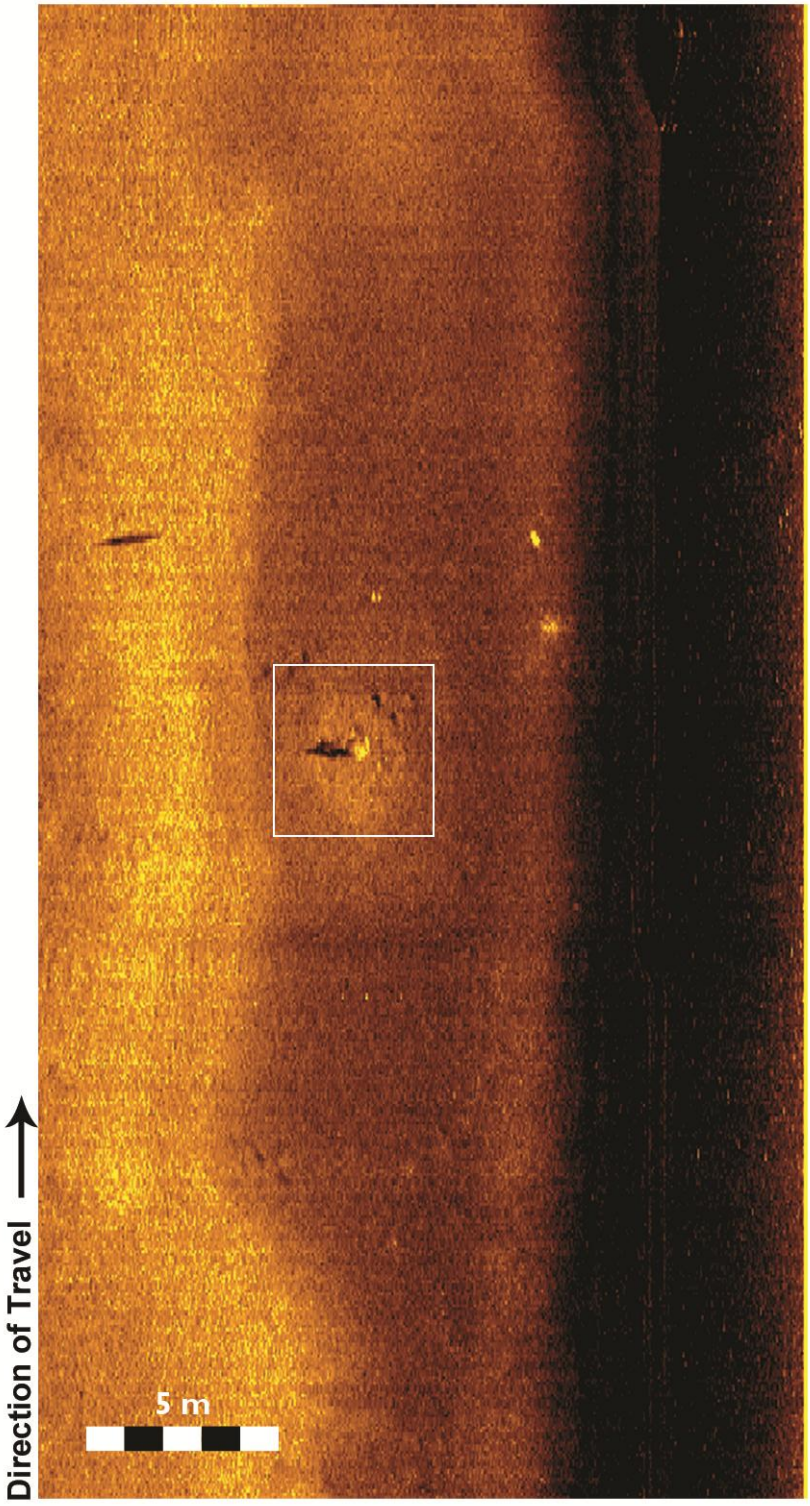

Figure 98: File 19Mar042, 1800 kHz, 20 m, signals transmitted to the left of the towfish. Pig carcass detected and scored as "poor."

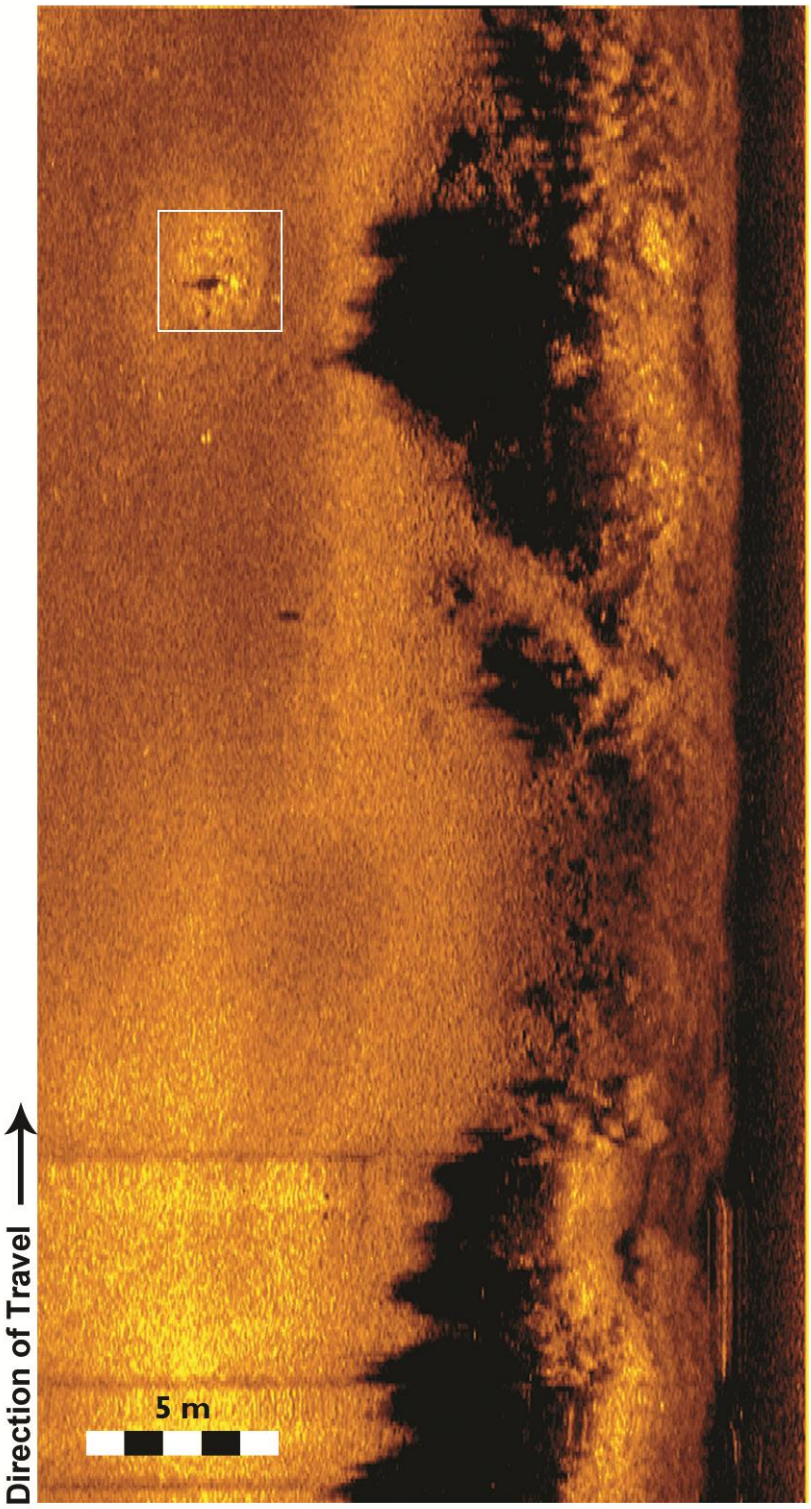

Figure 99: File02Apr008, 900 kHz, 20 m, signals transmitted to the left of the towfish. Pig carcass detected and scored as "poor."

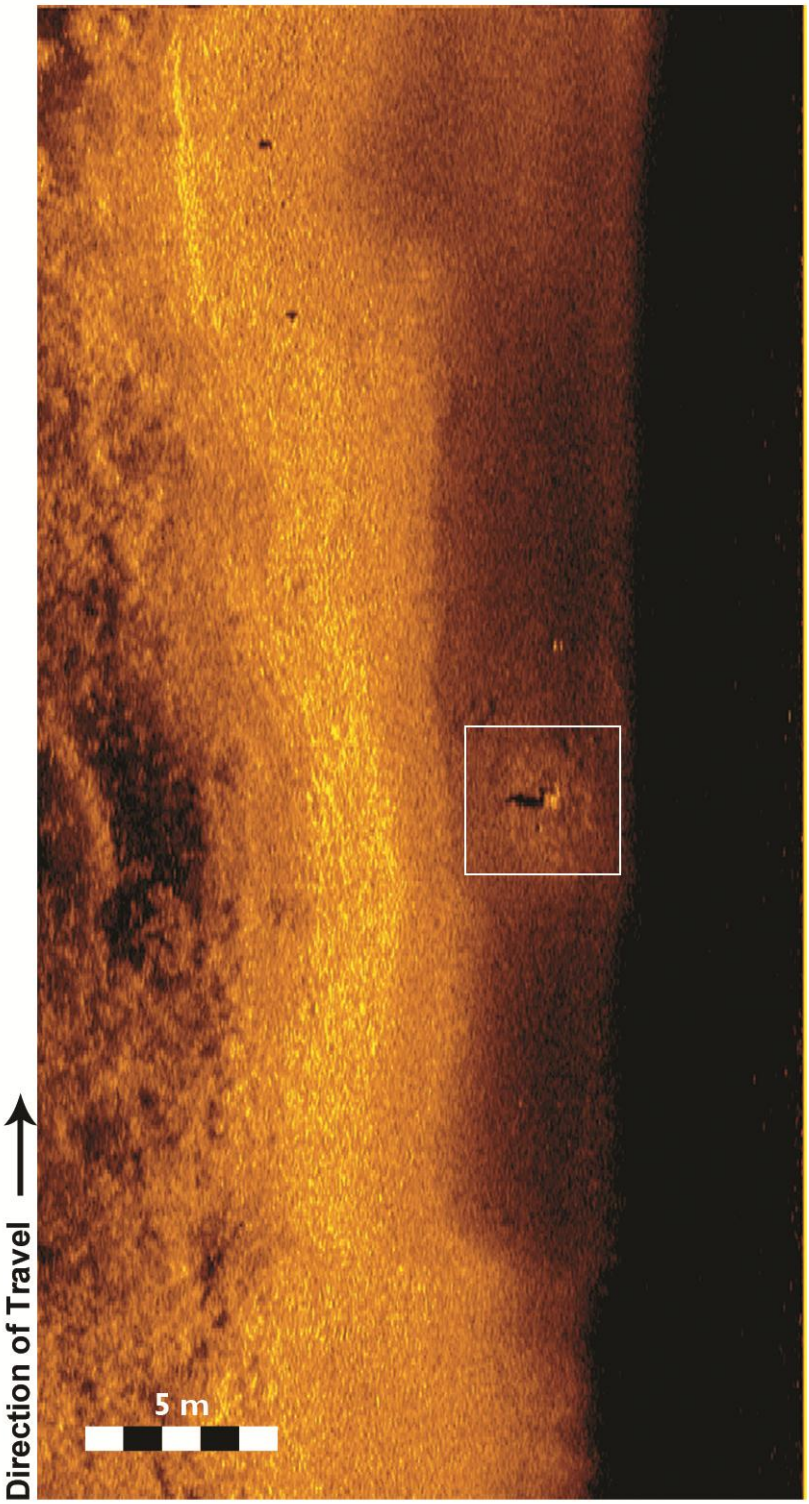

Figure 100: File02Apr033, 1800 kHz, 20 m, signals transmitted to the left of the towfish. Pig carcass detected and scored as "poor."

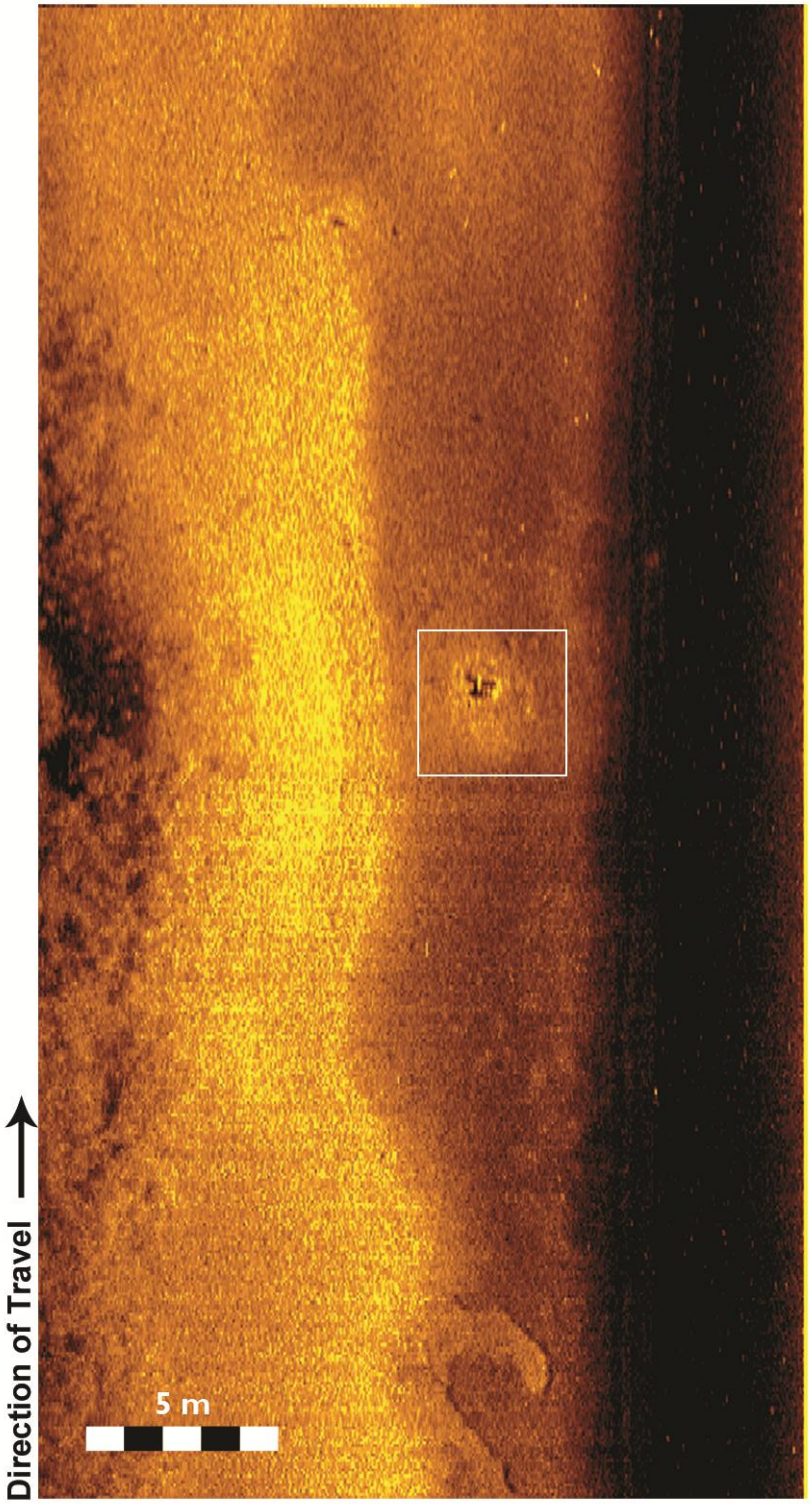

Figure 101: File 17Apr015, 900 kHz, 20 m, signals transmitted to the left of the towfish. Pig carcass detected and scored as "poor."

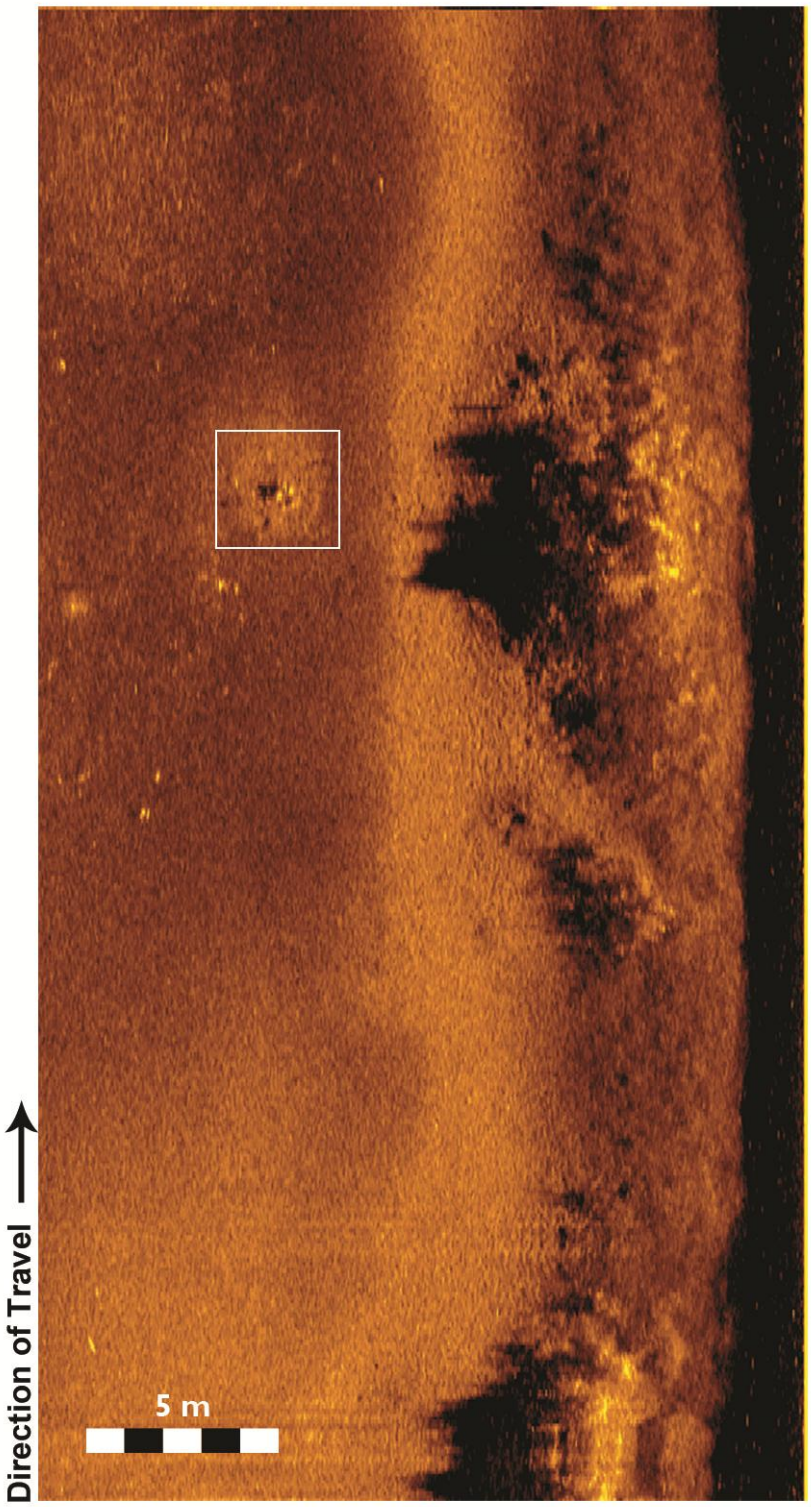

Figure 102: File 17Apr033, 1800 kHz, 20 m, signals transmitted to the left of the towfish. Pig carcass detected and scored as "poor."

APPENDIX F: SONAR IMAGES FROM PIG 2B

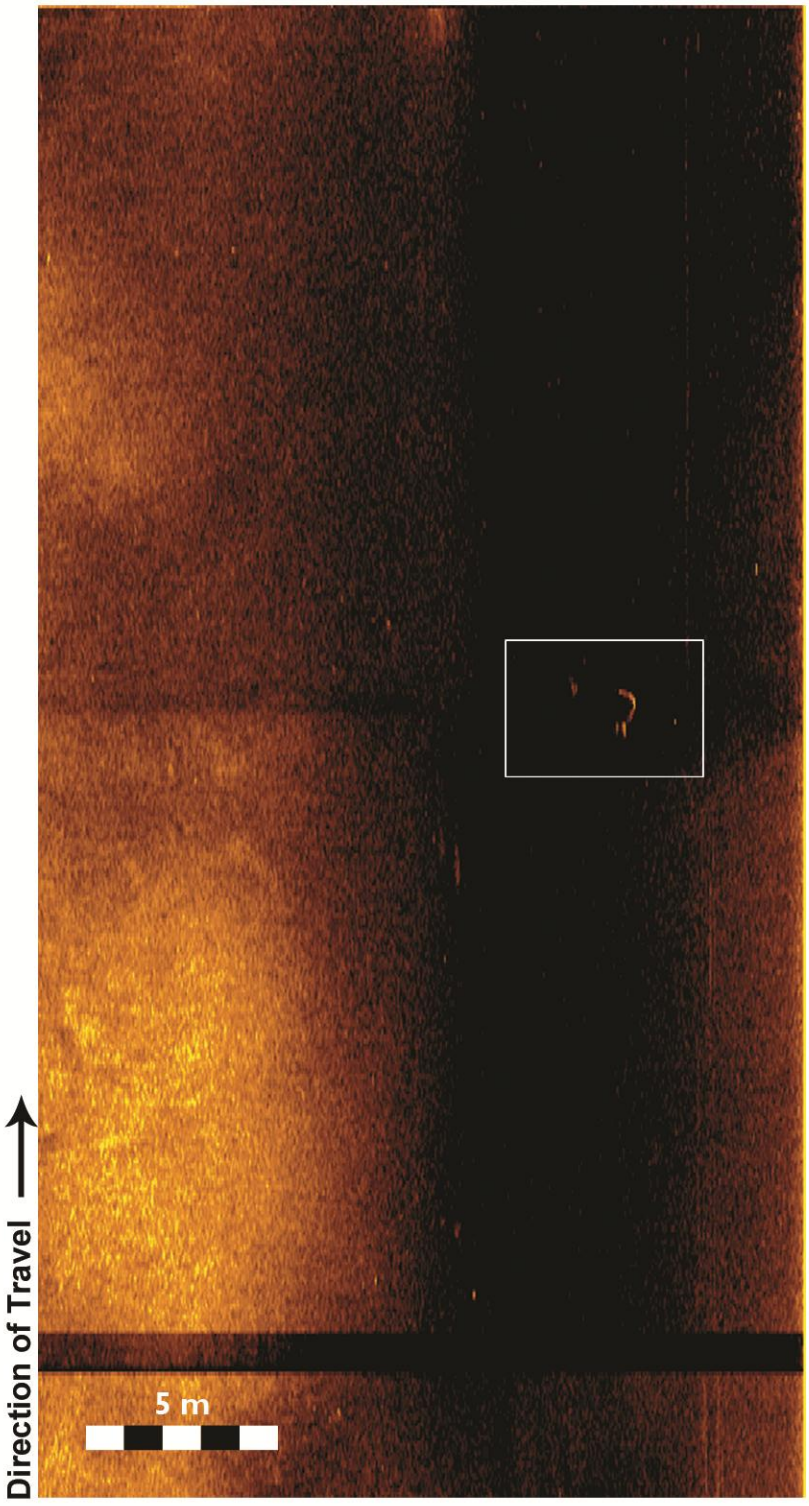

Figure 103: File 27Jan047, 900 kHz, 20 m, acoustic signals transmitted out of the left side of the towfish. Pig carcass detected, and score as "poor."

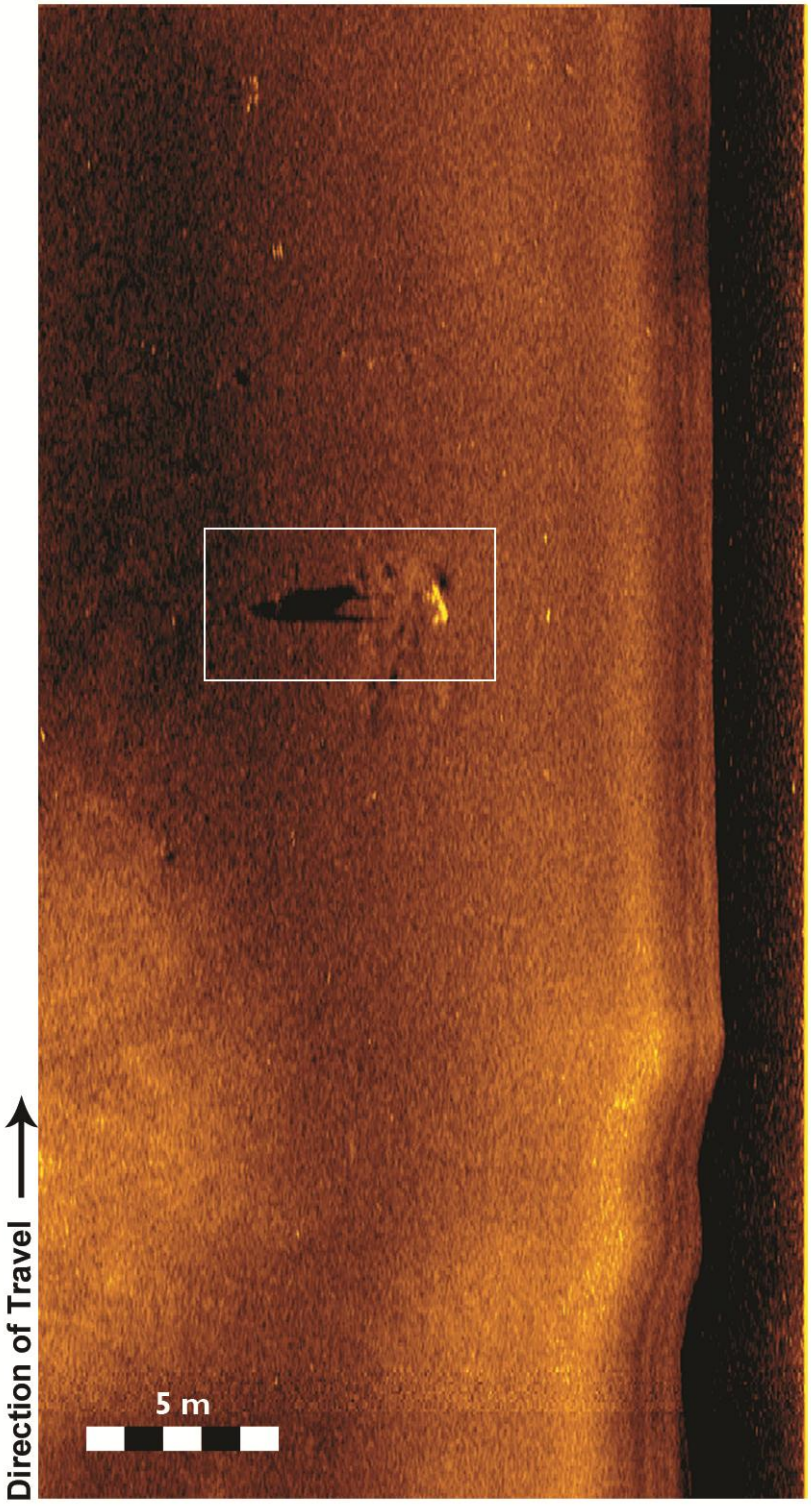

Figure 104: File 02Feb010, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "excellent."

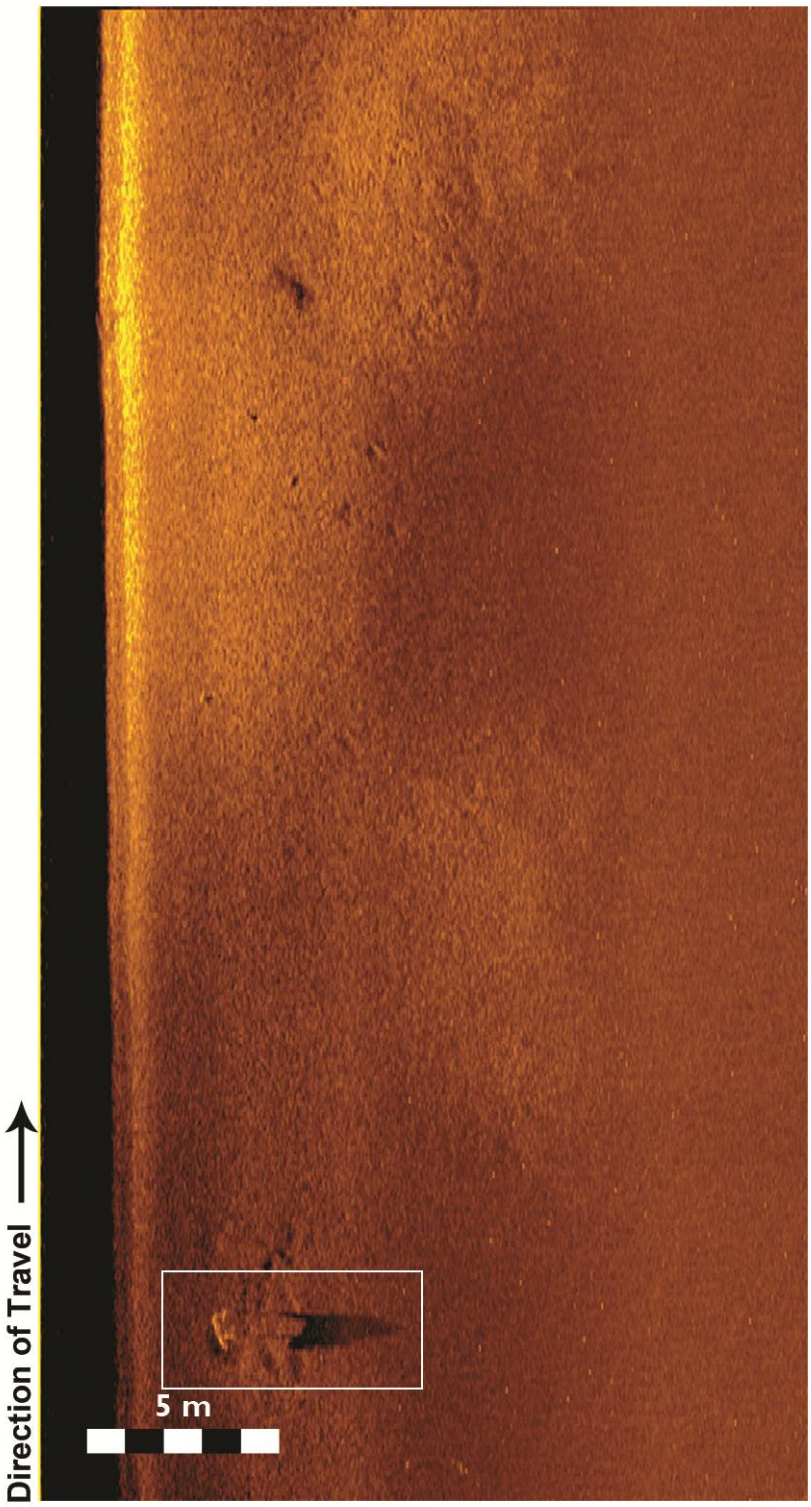

Figure 105: File 02Feb042, 1800 kHz, 20 m, signals transmitted out of the right side of the towfish. Pig carcass detected and scored as "excellent."

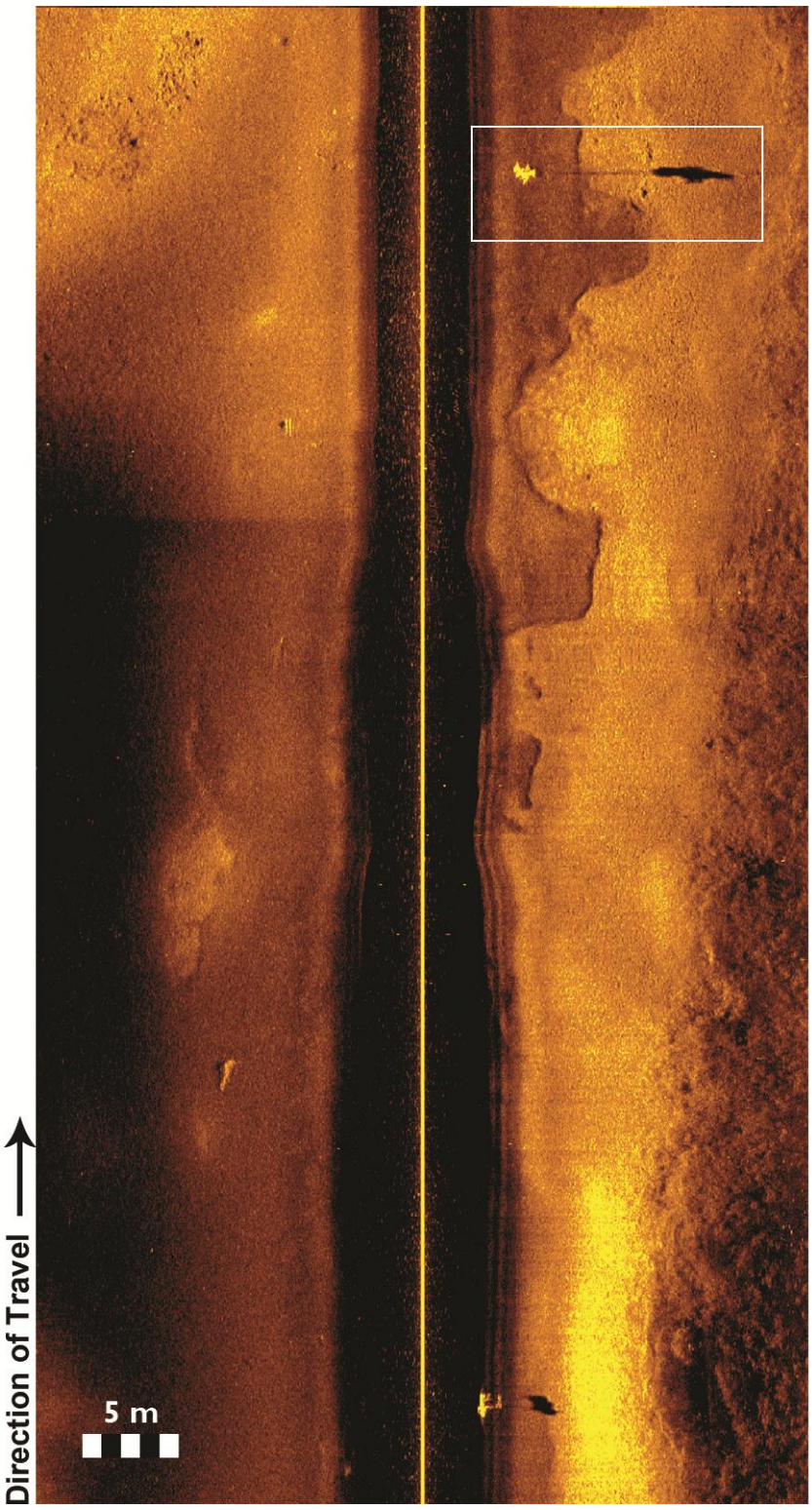

Figure 106: File 07Feb266, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [top] detected and scored as "excellent."

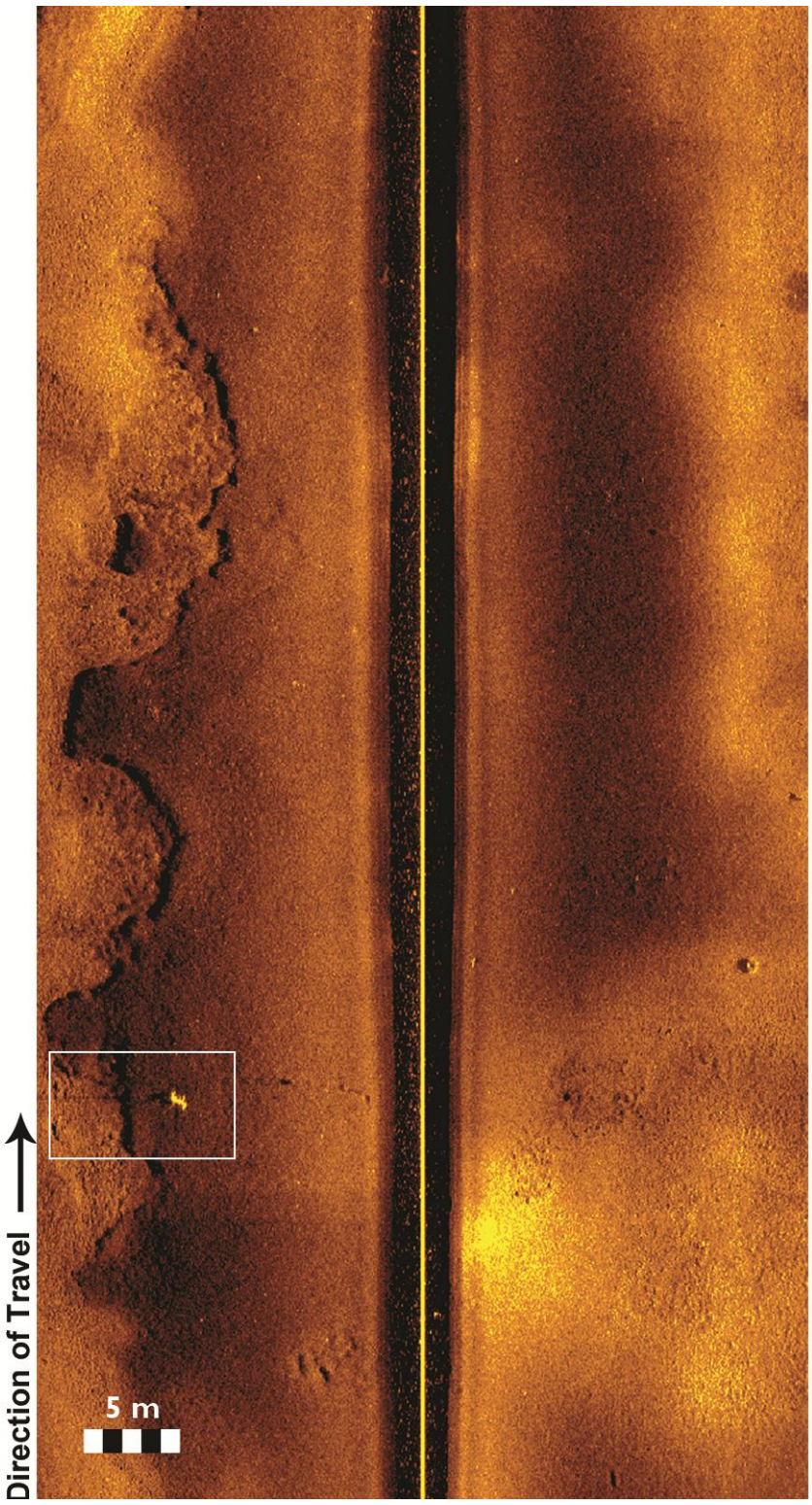

Figure 107: File 07Feb277, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

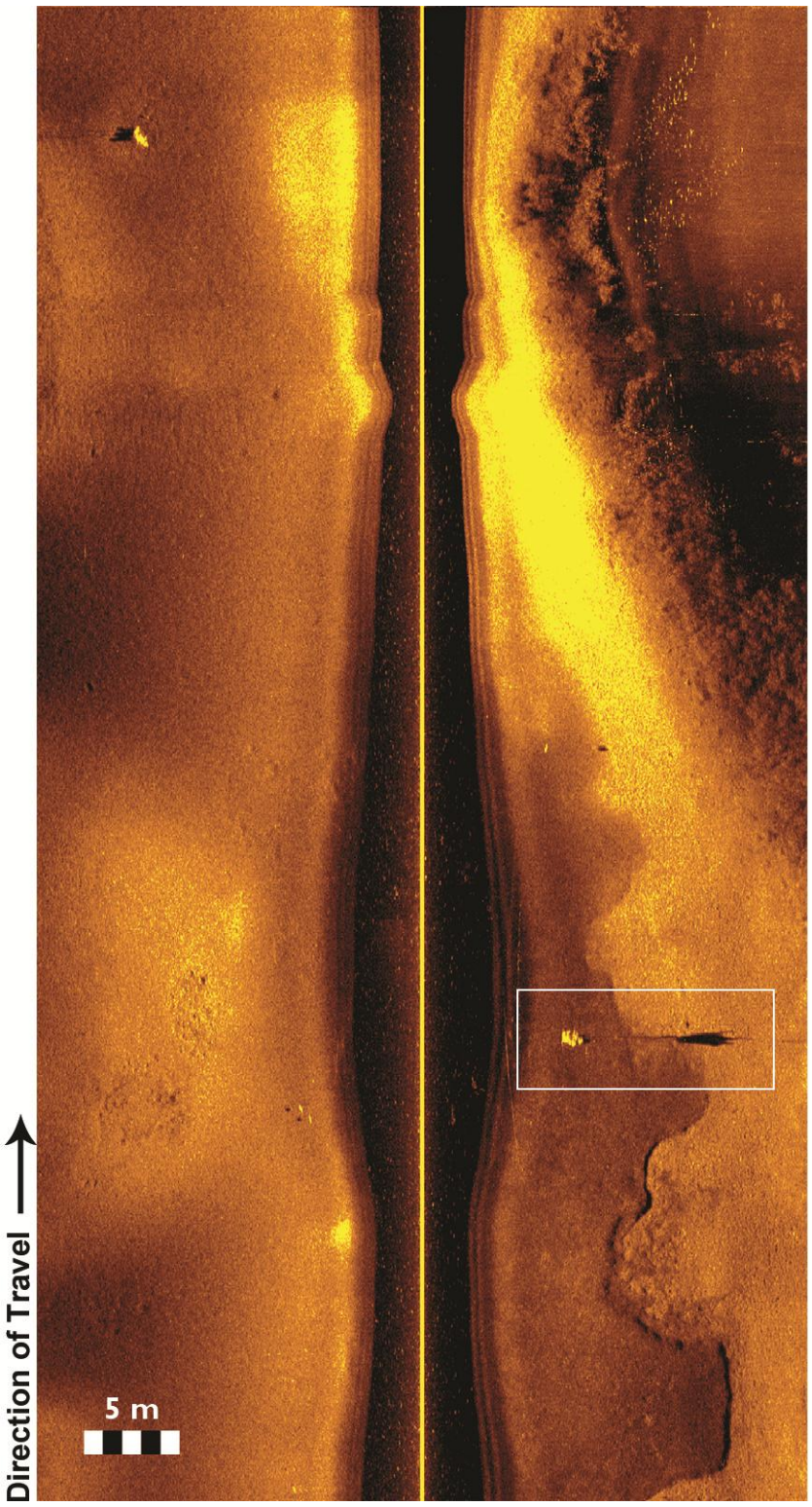

Figure 108: File 16Feb006, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [bottom] detected and scored as "good."

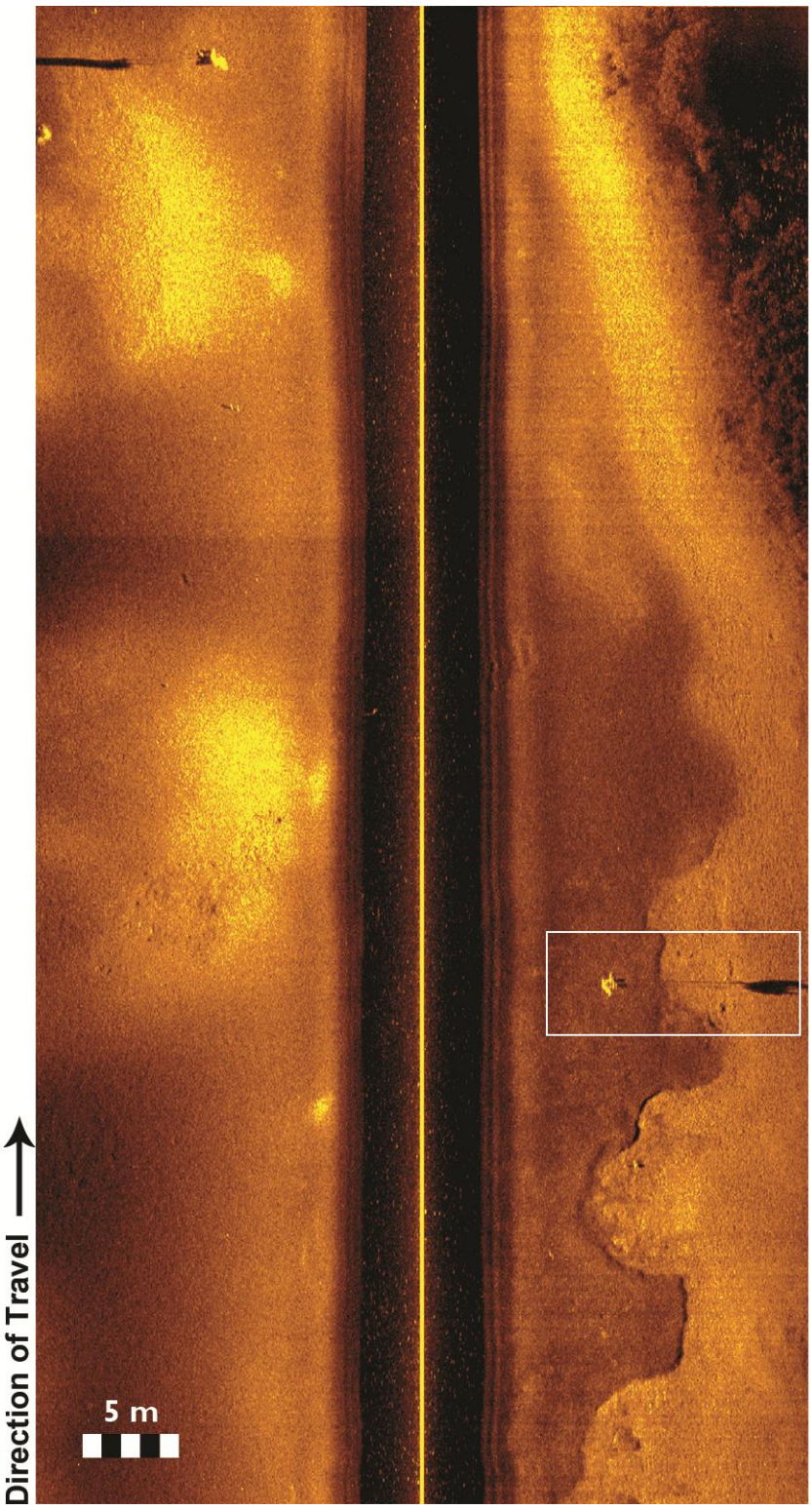

Figure 109: File 16Feb013, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [bottom] detected and scored as "good."

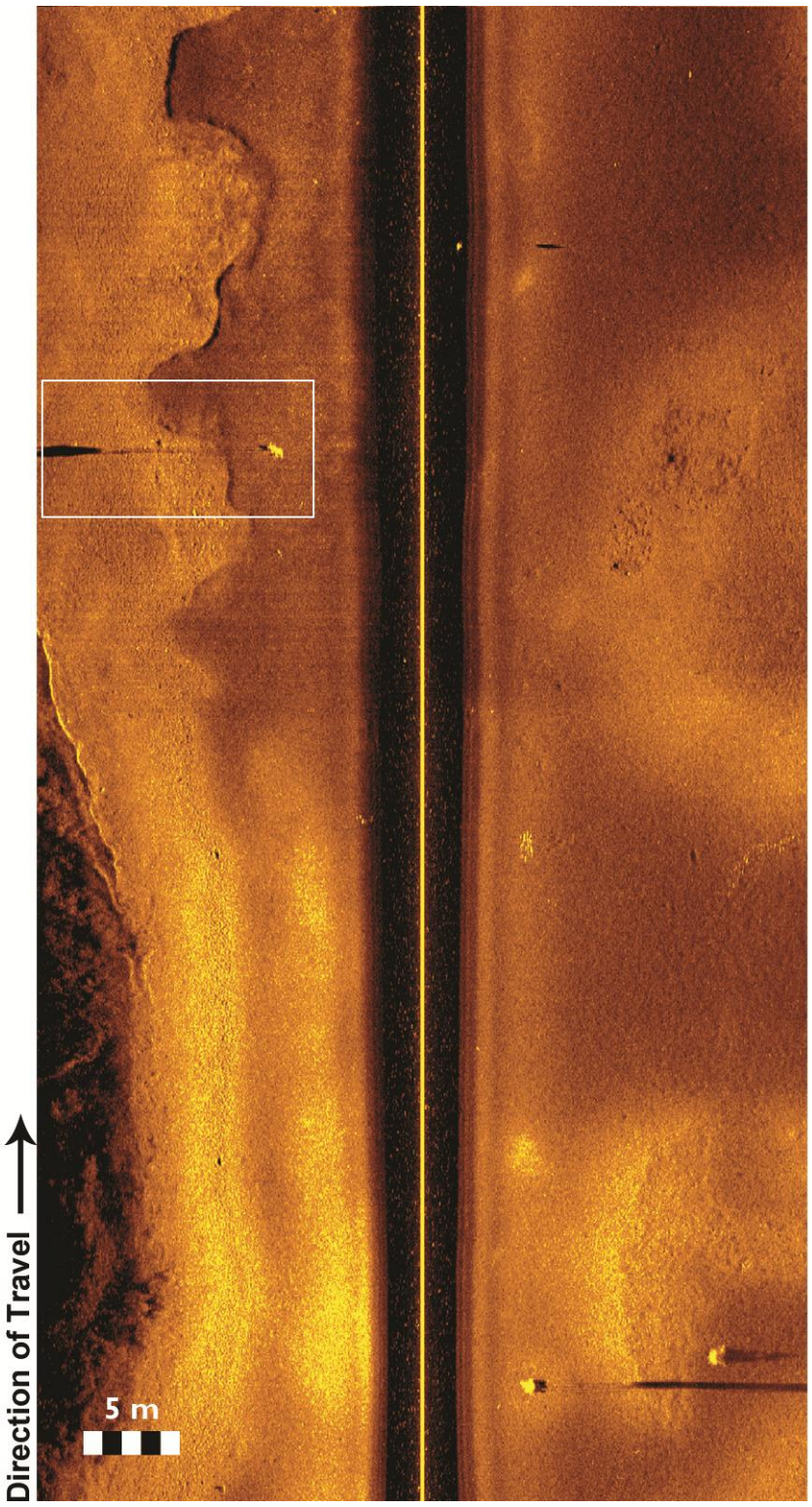

Figure 110: File 28Feb008, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [top] detected and scored as "excellent."

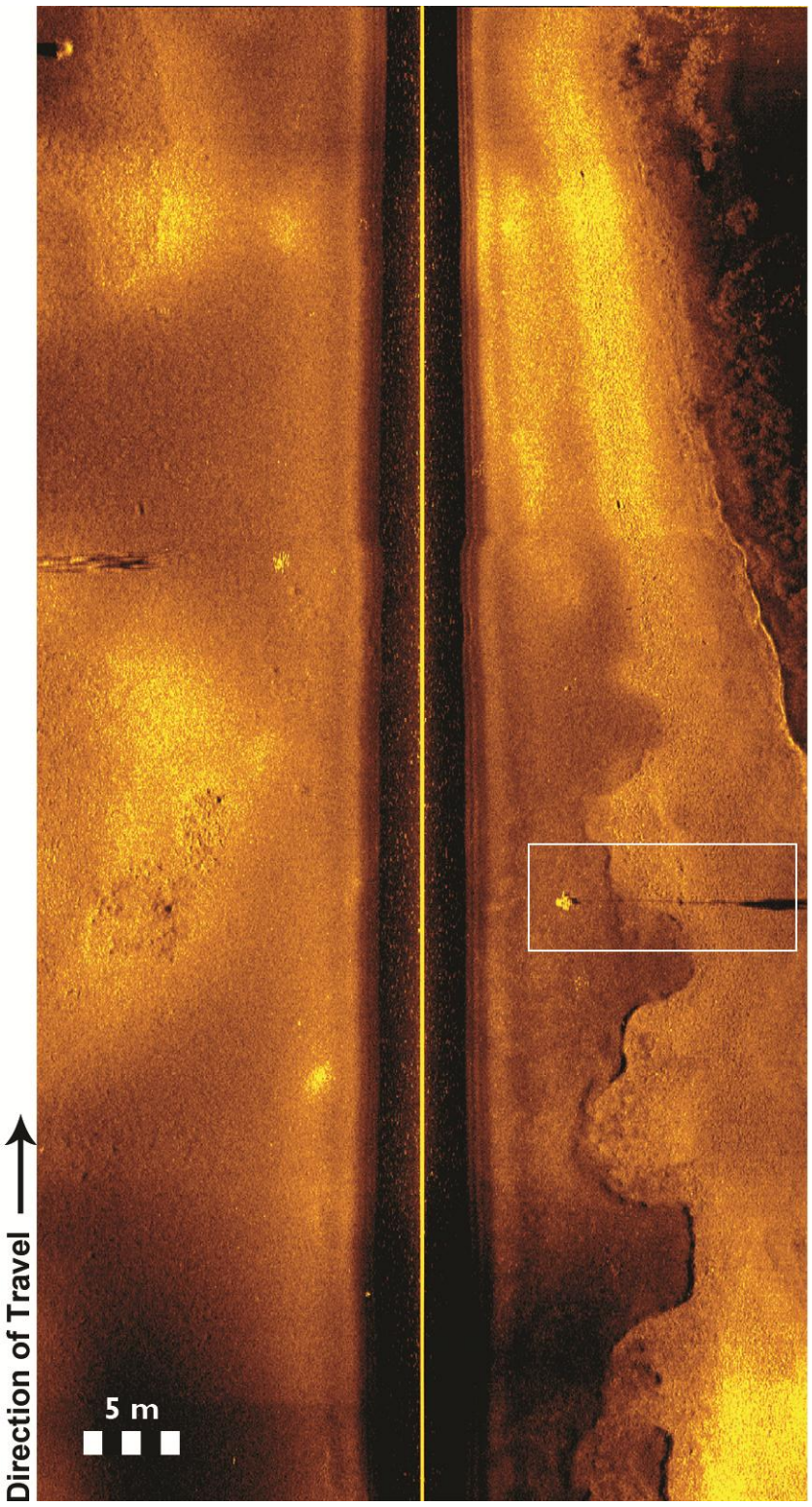

Figure 111: File 28Feb012, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

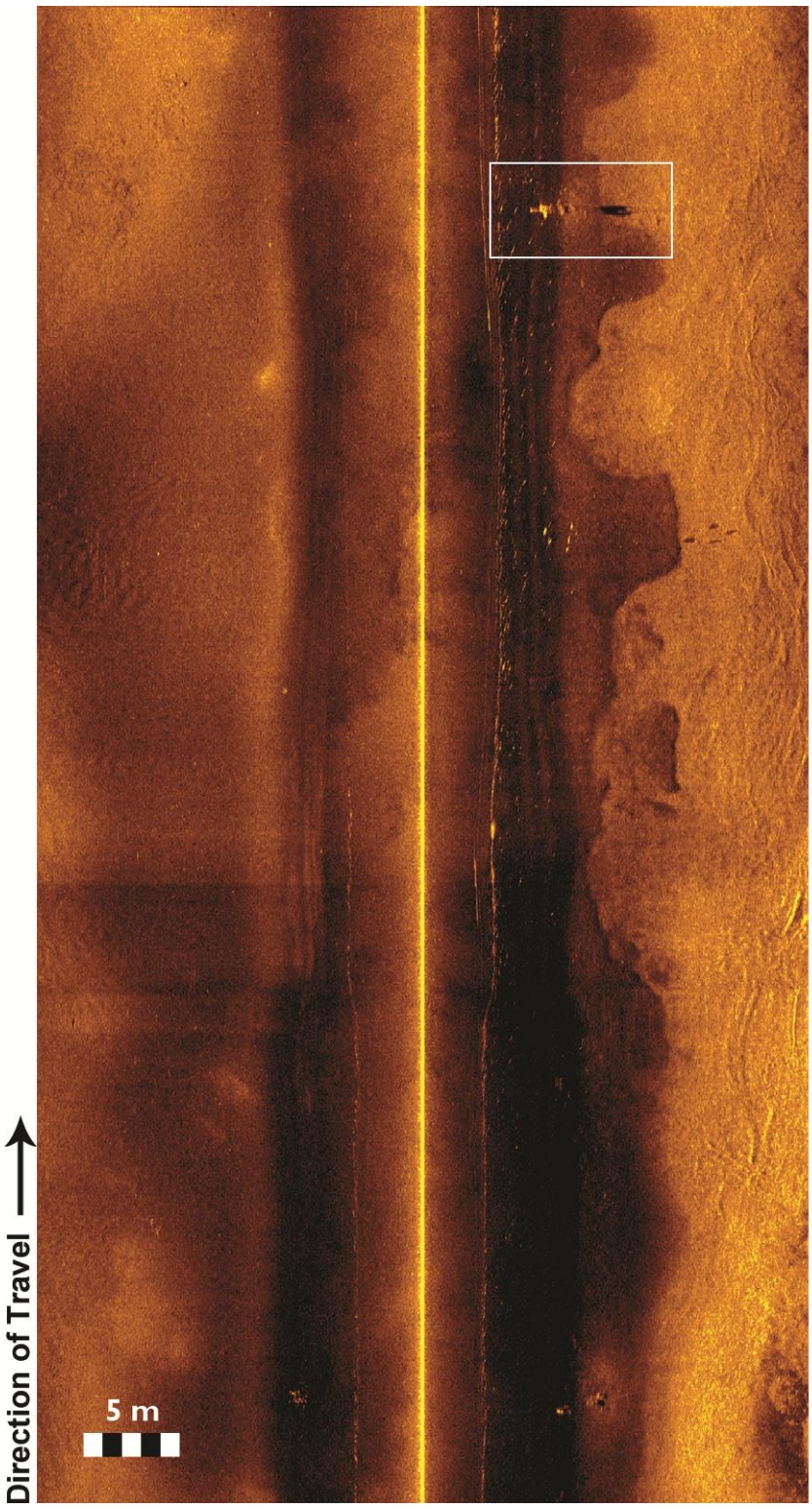

Figure 112: File 06Mar012, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

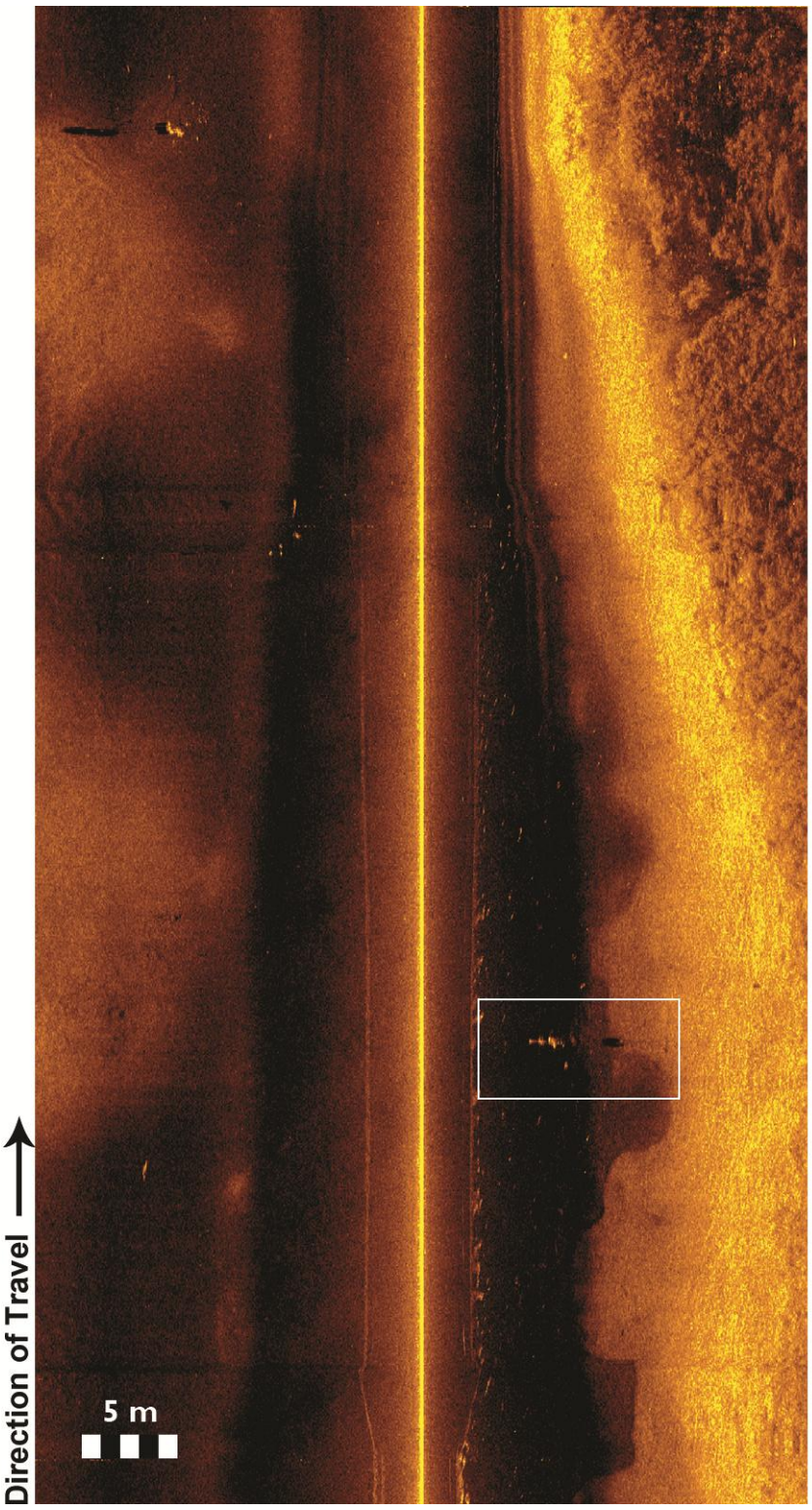

Figure 113: File 06Mar006, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [bottom] detected and scored as "poor."

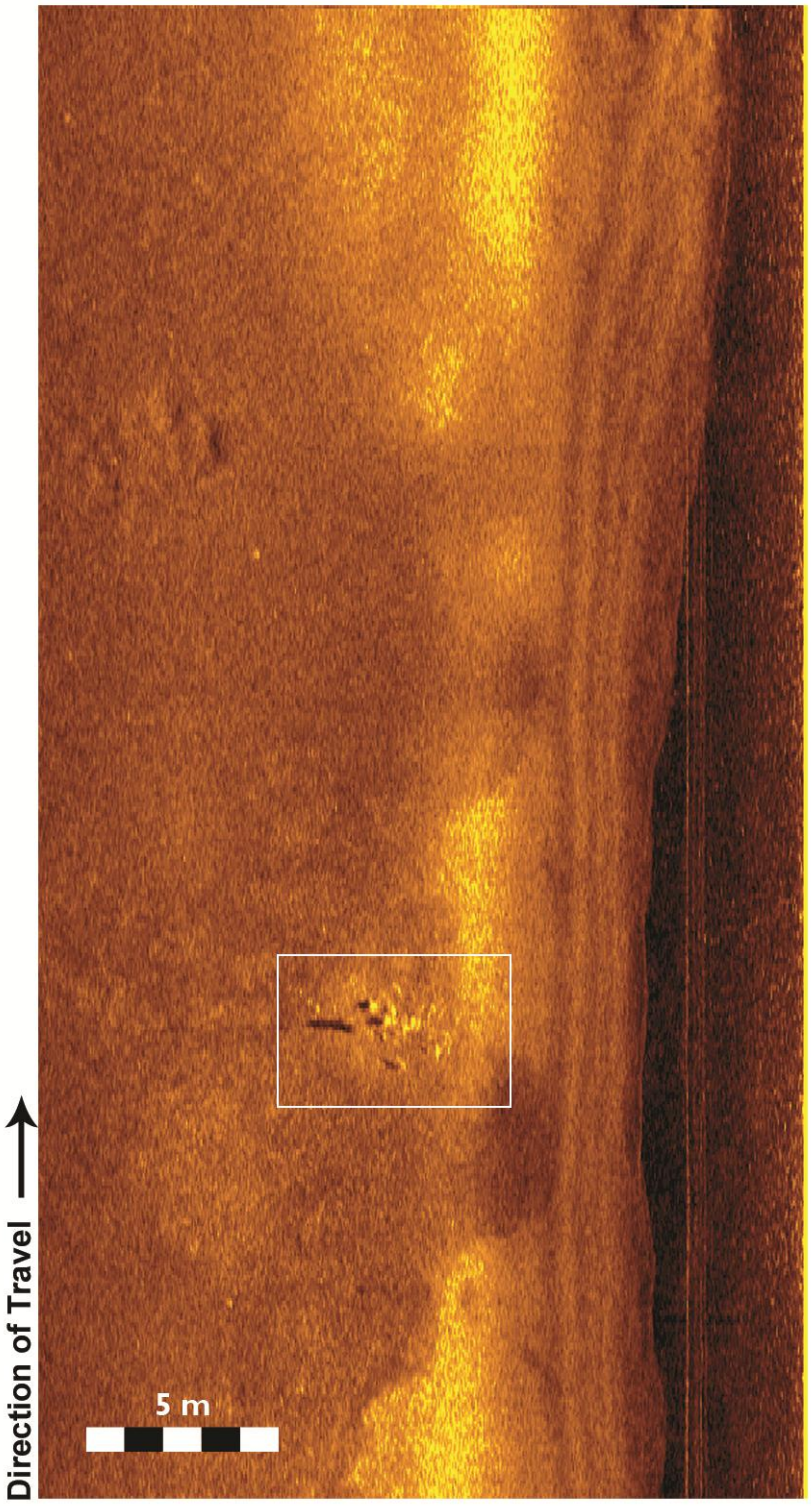

Figure 114: File 19Mar016, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

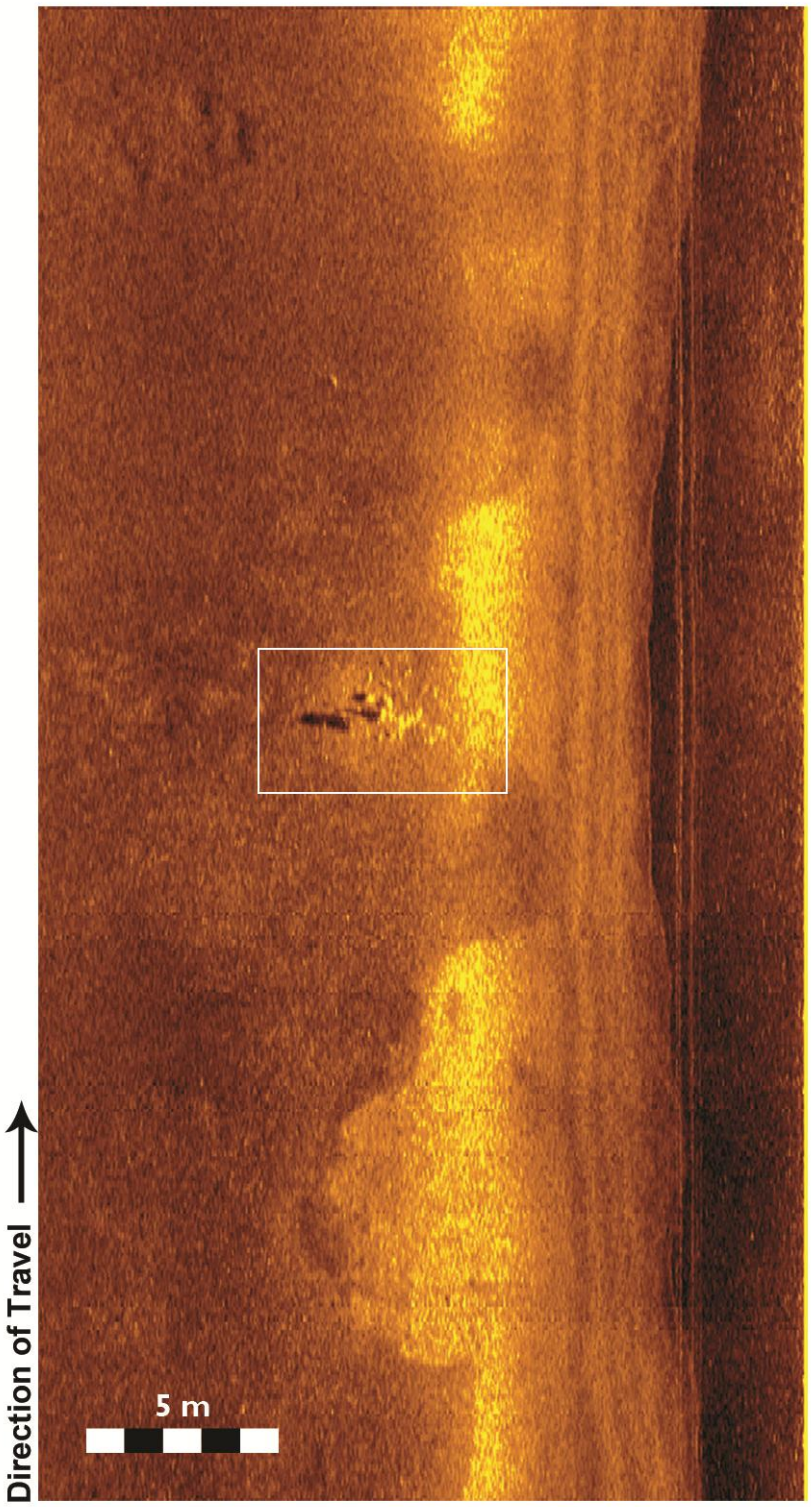

Figure 115: File 19Mar031, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

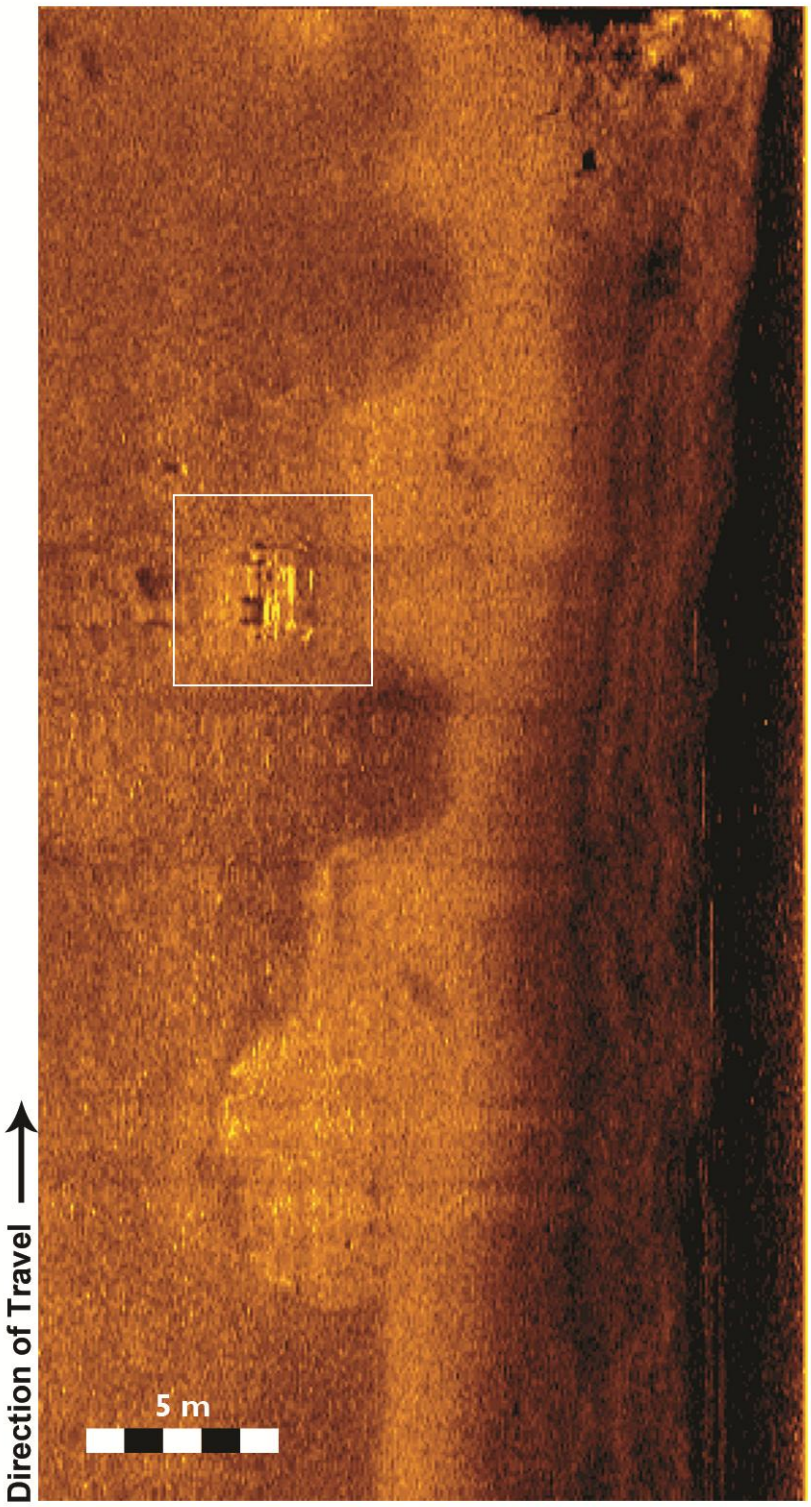

Figure 116: File 02Apr010, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

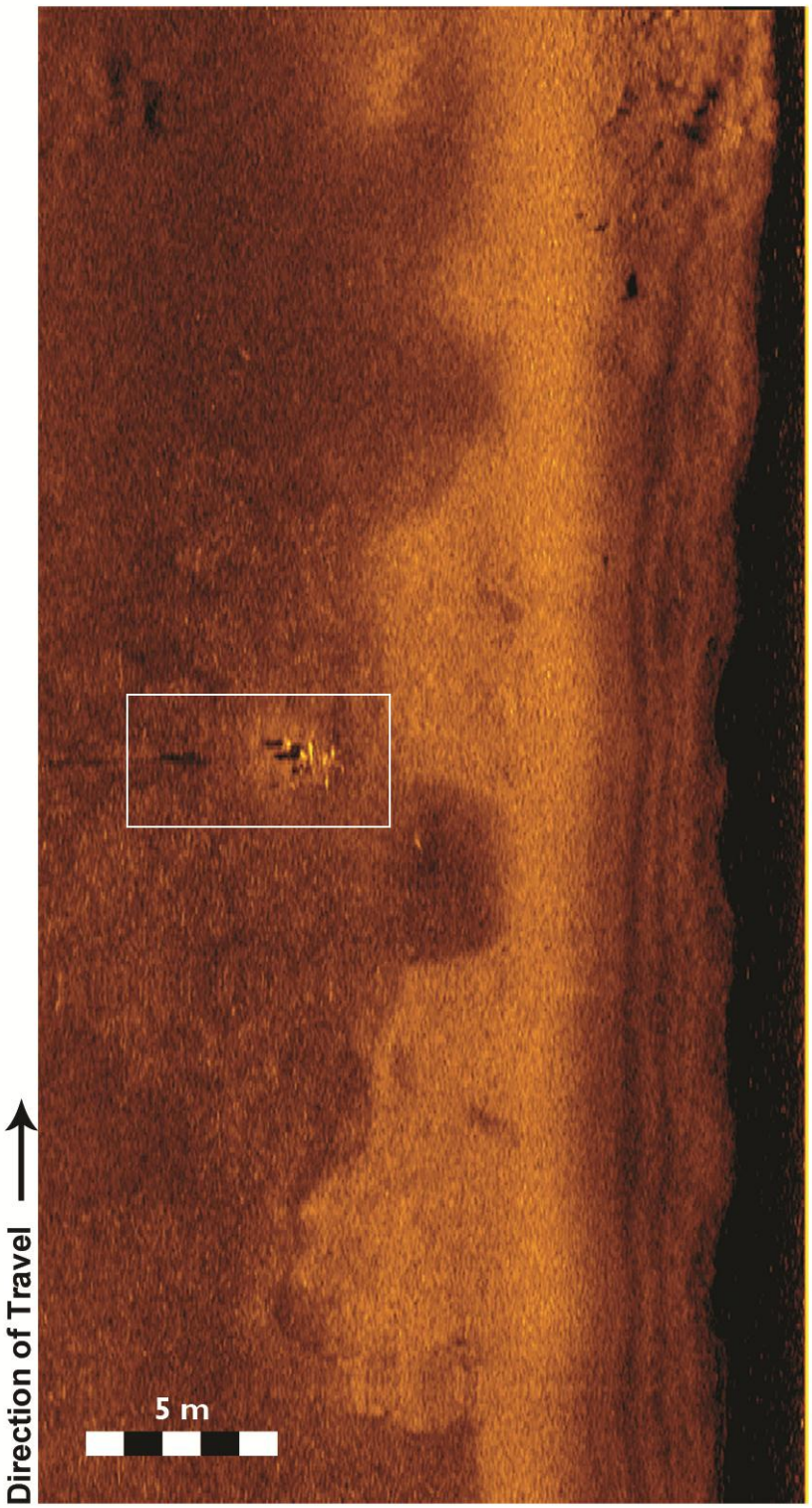

Figure 117: File 02Apr024, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

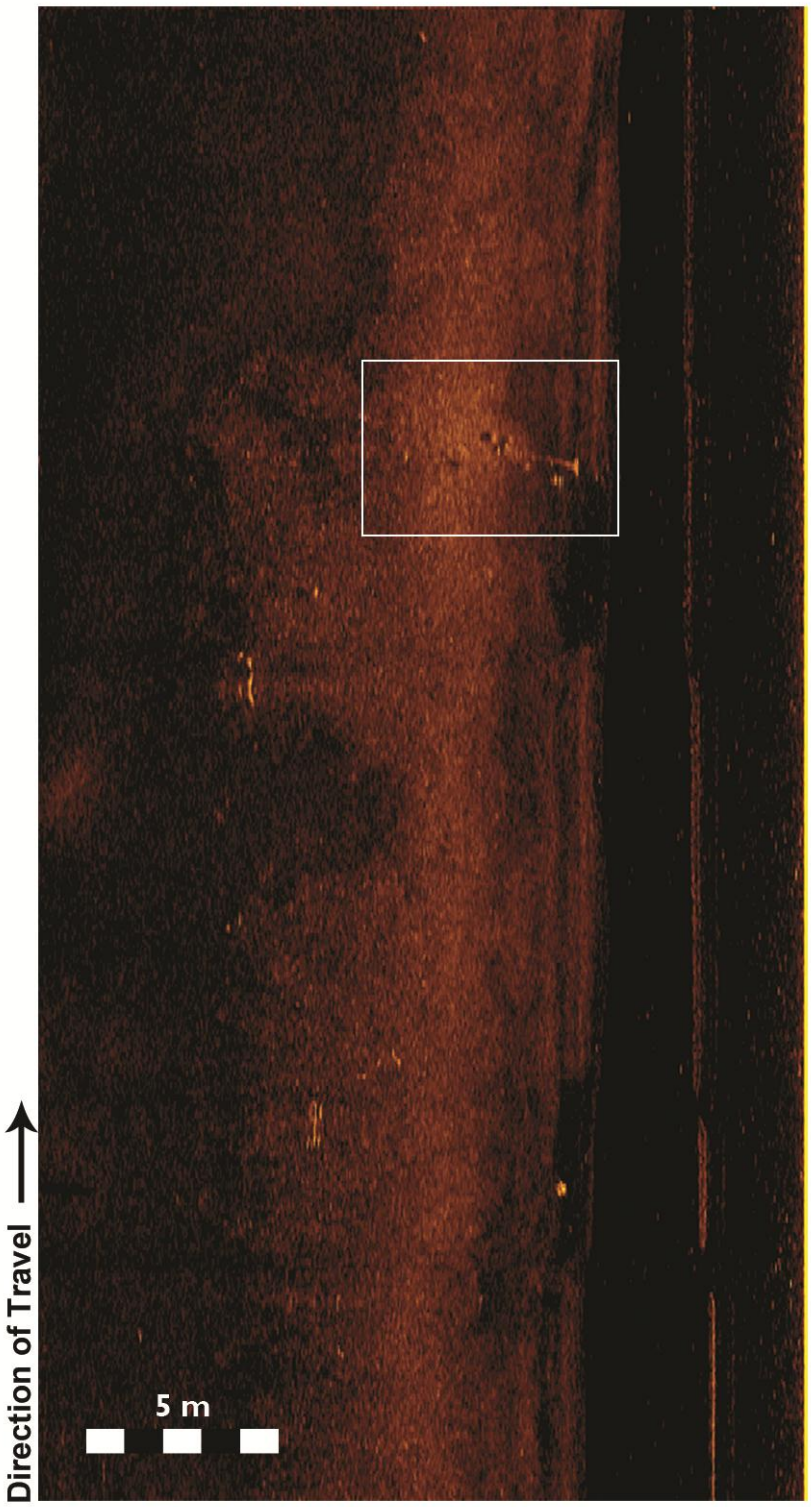

Figure 118: File 17Apr006, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

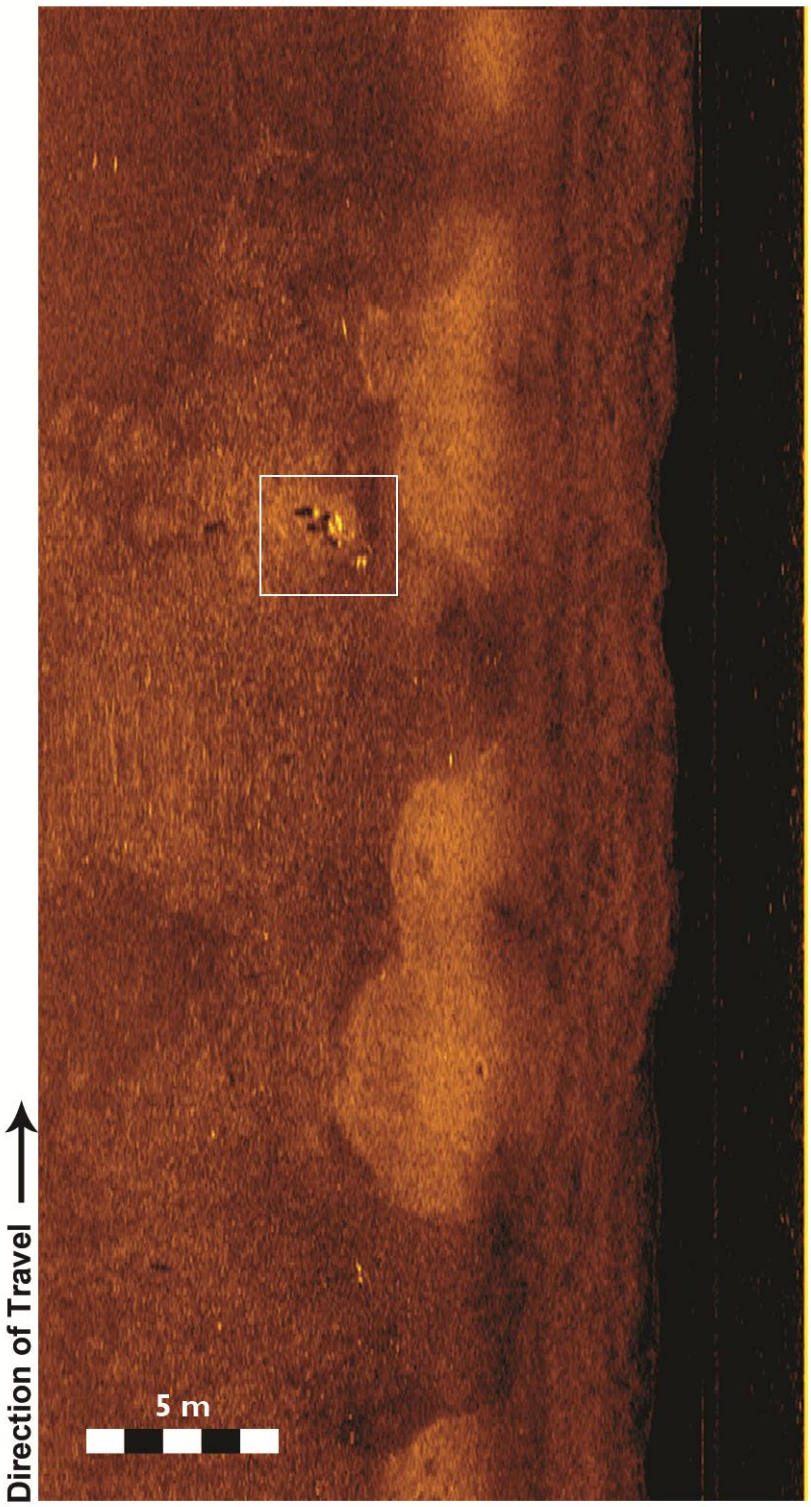

Figure 119: File 17Apr035, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

APPENDIX G: SONAR IMAGES FROM PIG 2C

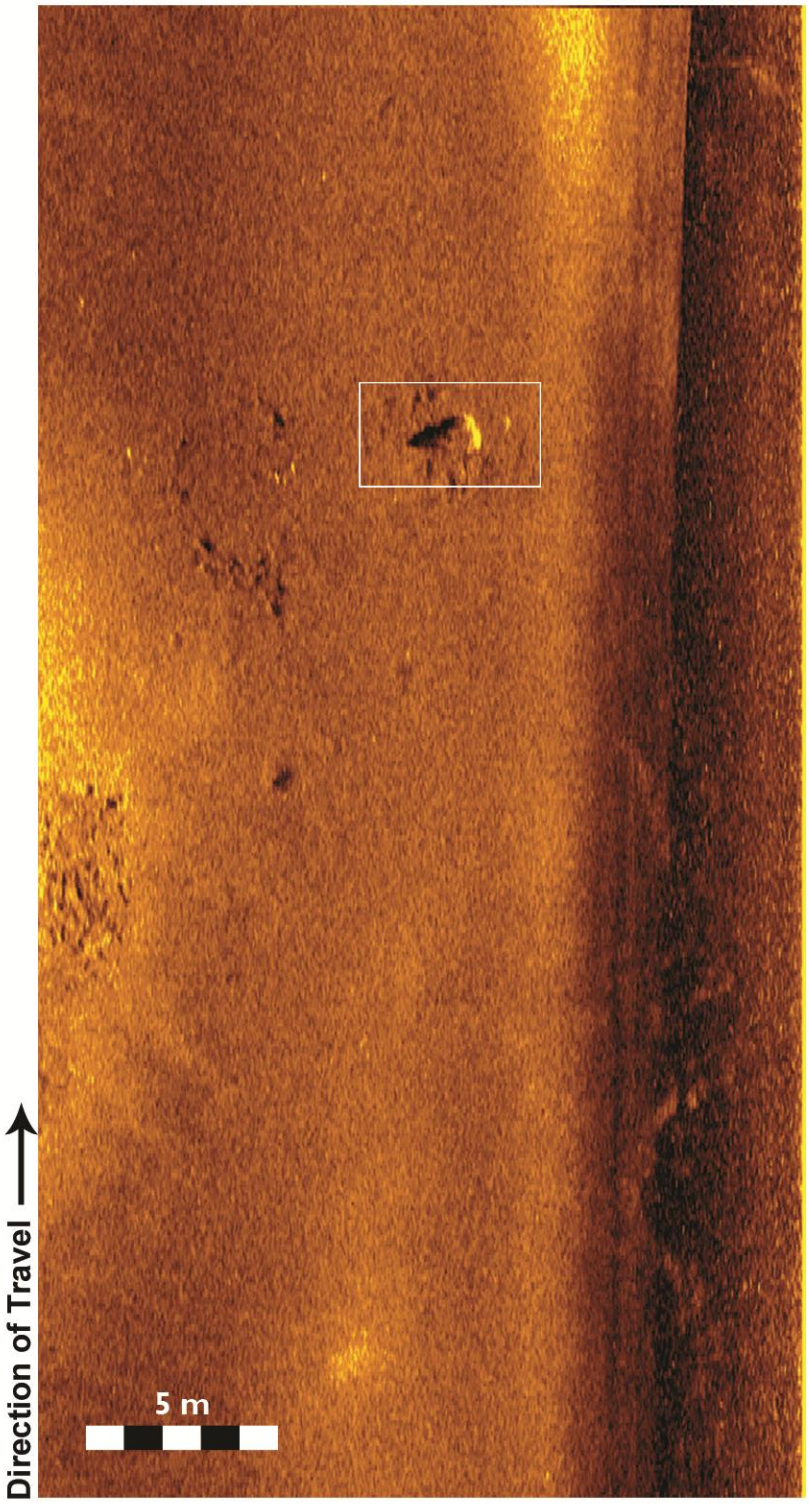

Figure 120: File 27Jan049, 900 kHz, 20 m, acoustic signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "excellent."

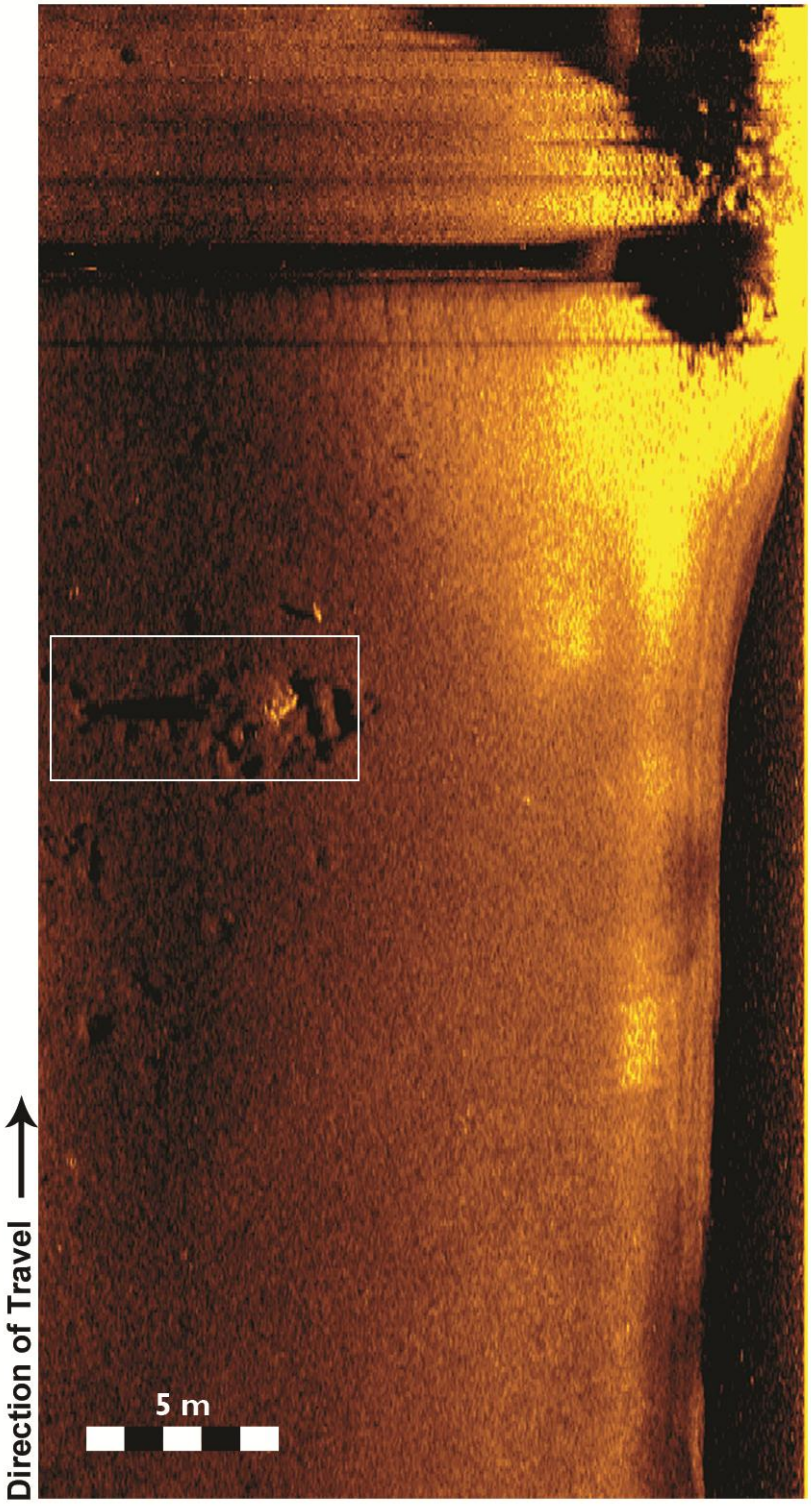

Figure 121: File 02Feb012, 900 kHz, 20 m, signals transmitted to the right of the towfish. Pig carcass detected and scored as "excellent."

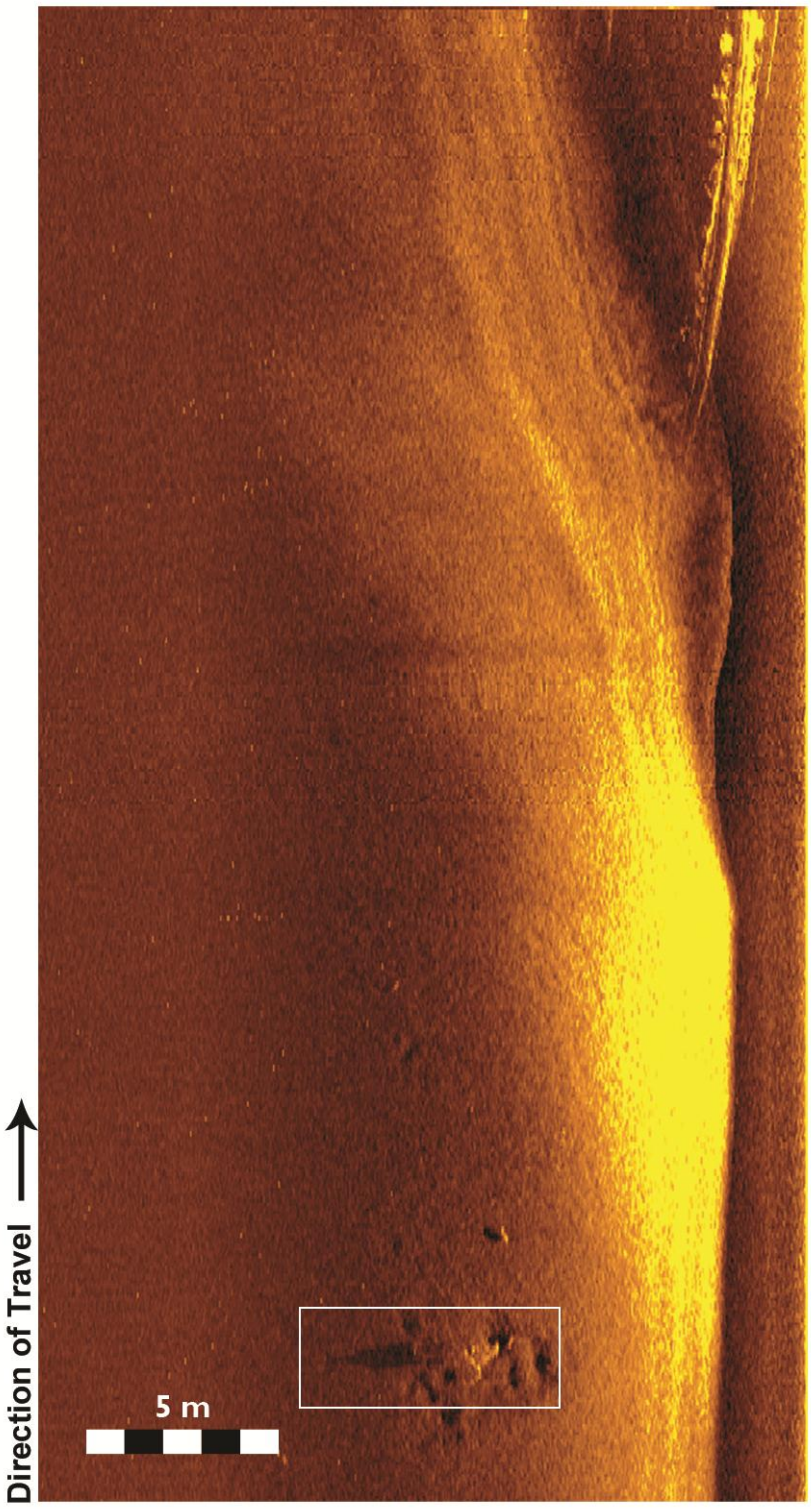

Figure 122: File 02Feb034, 1800 kHz, 20 m, signals transmitted out of left side of the towfish. Pig carcass detected and scored as "excellent."

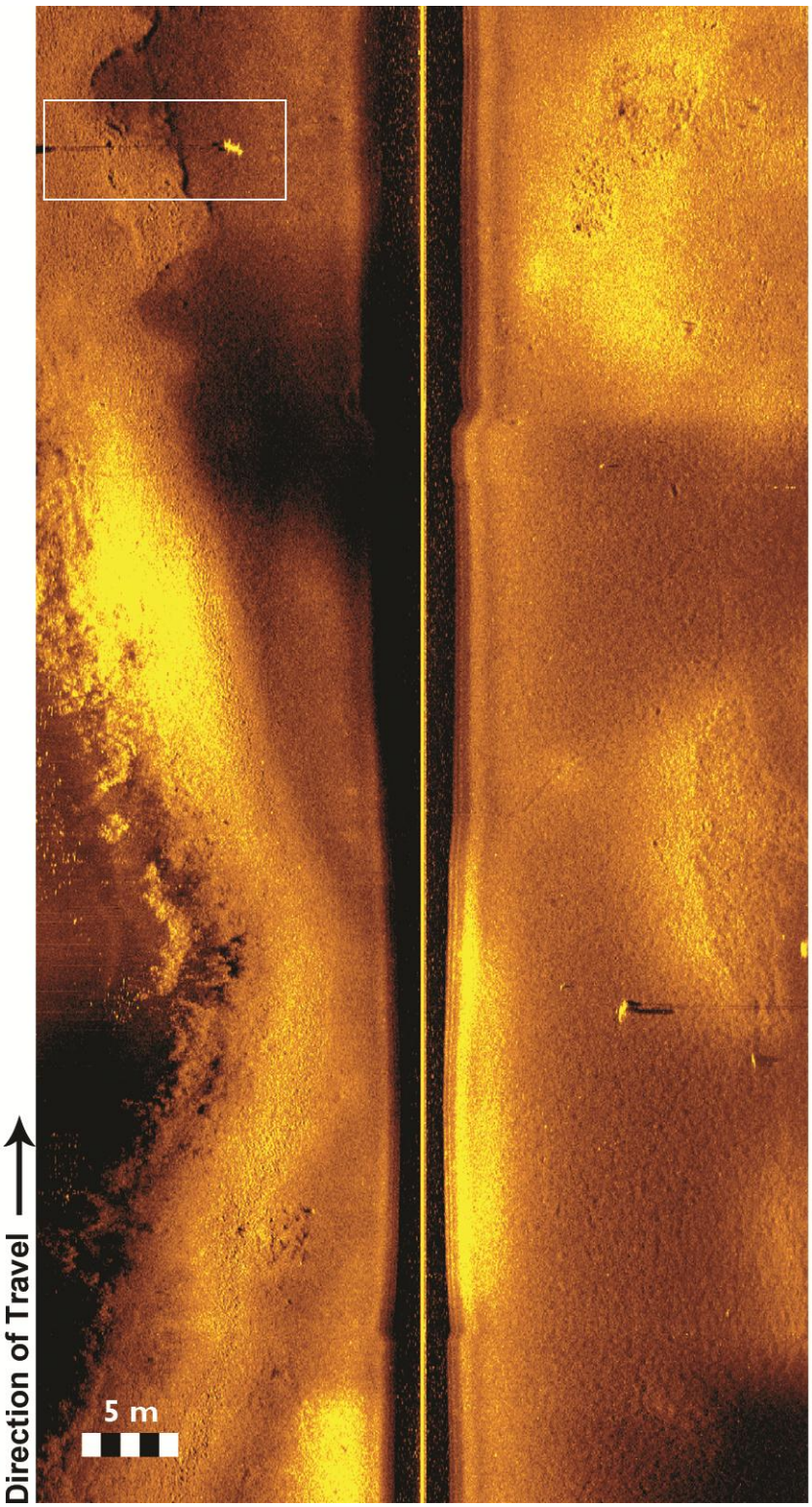

Figure 123: File 07Feb262, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [top] is detected and scored as "good."

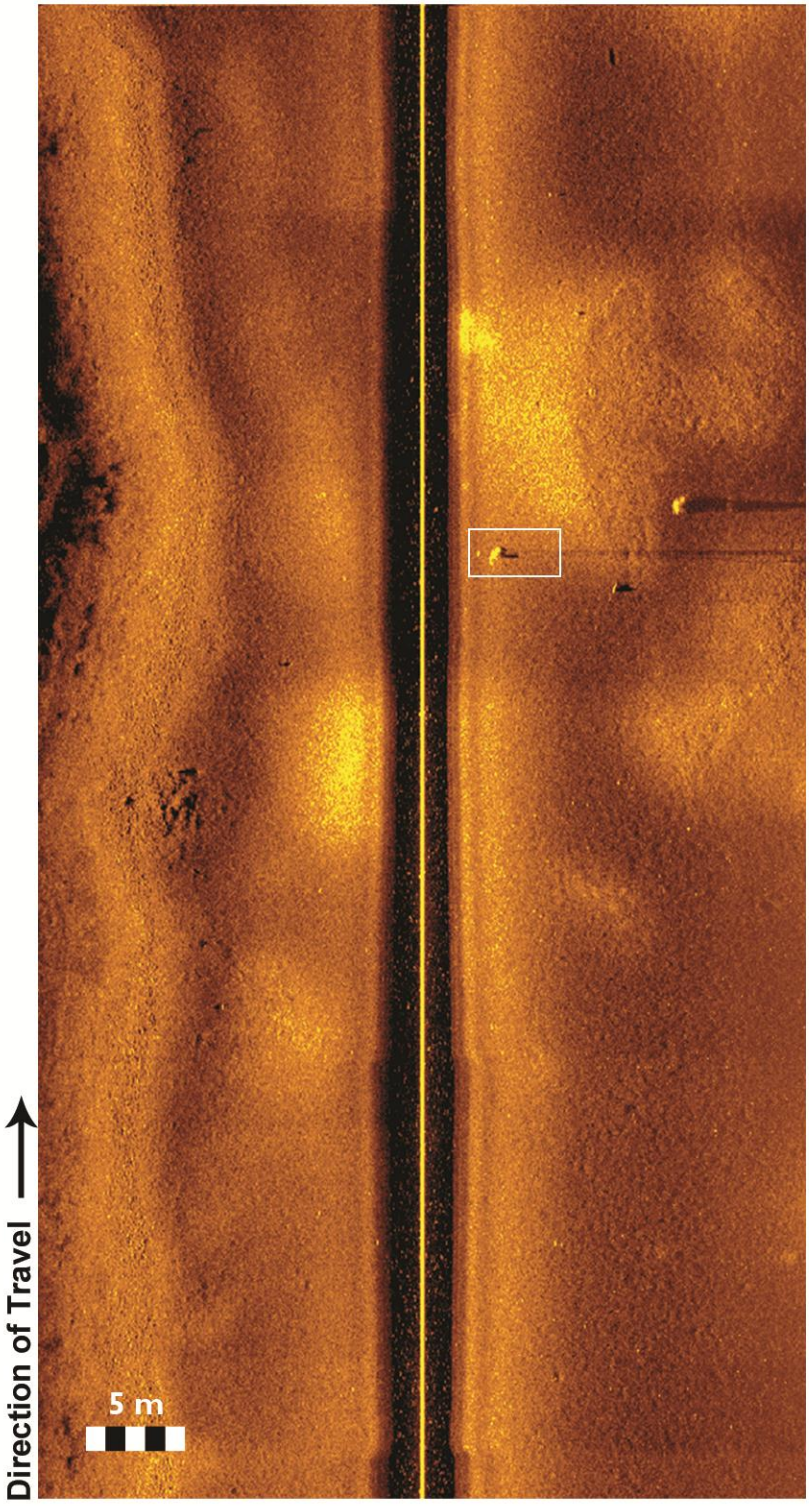

Figure 124: File 07Feb276, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish, Pig carcass detected and scored as "good."

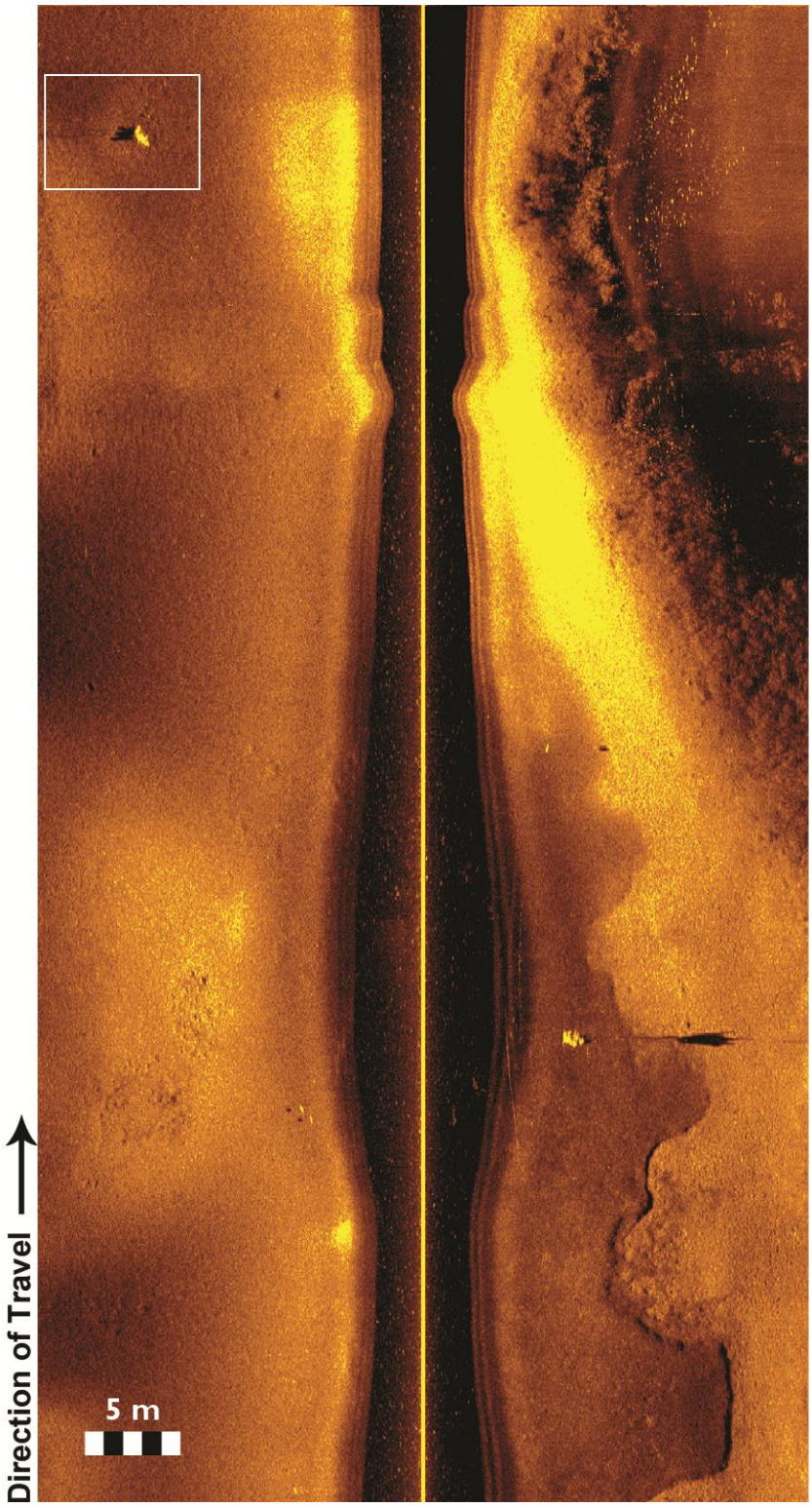

Figure 125: File 16Feb006, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [top] is detected and scored as "good."

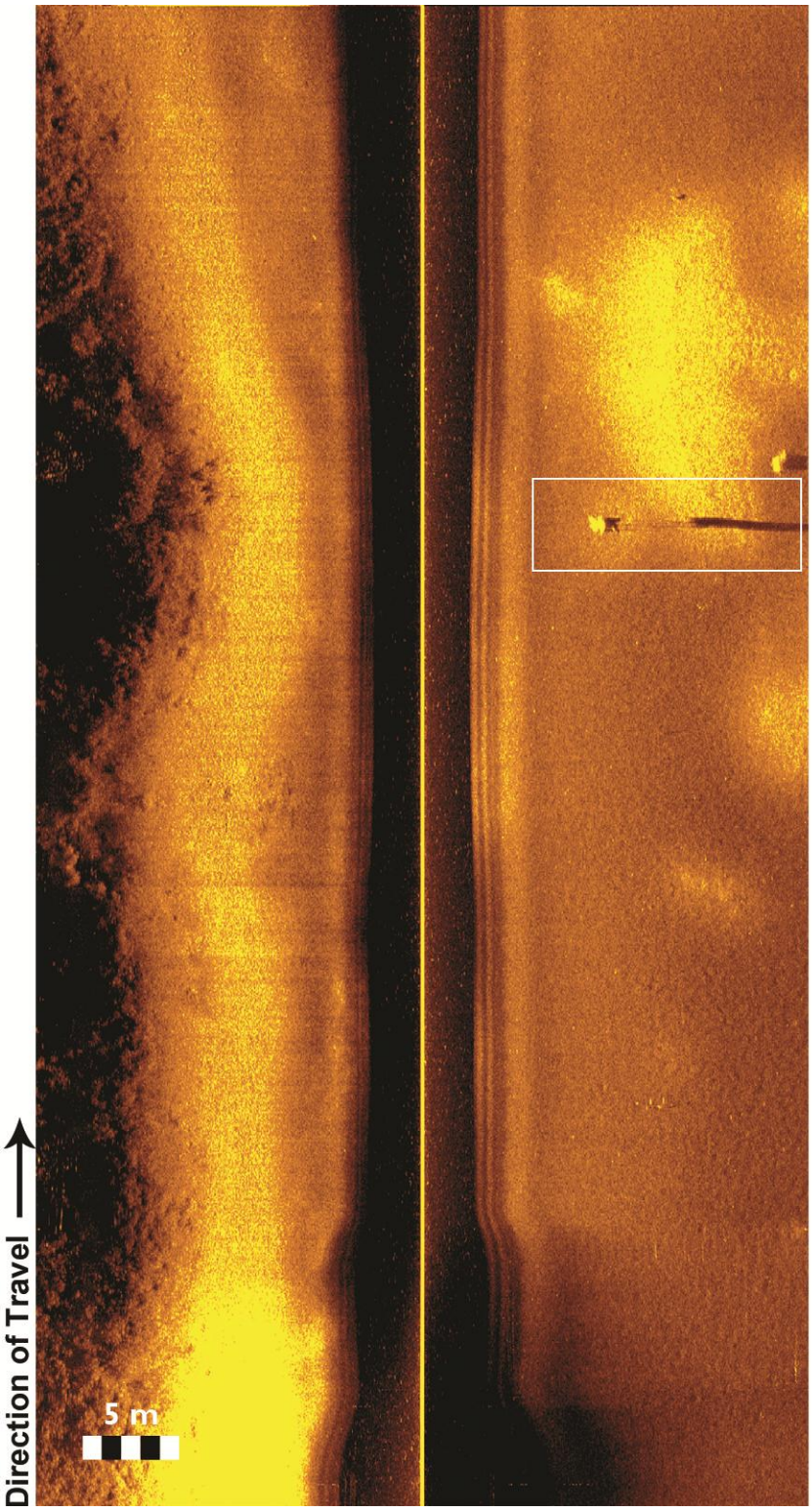

Figure 126: File 16Feb015, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

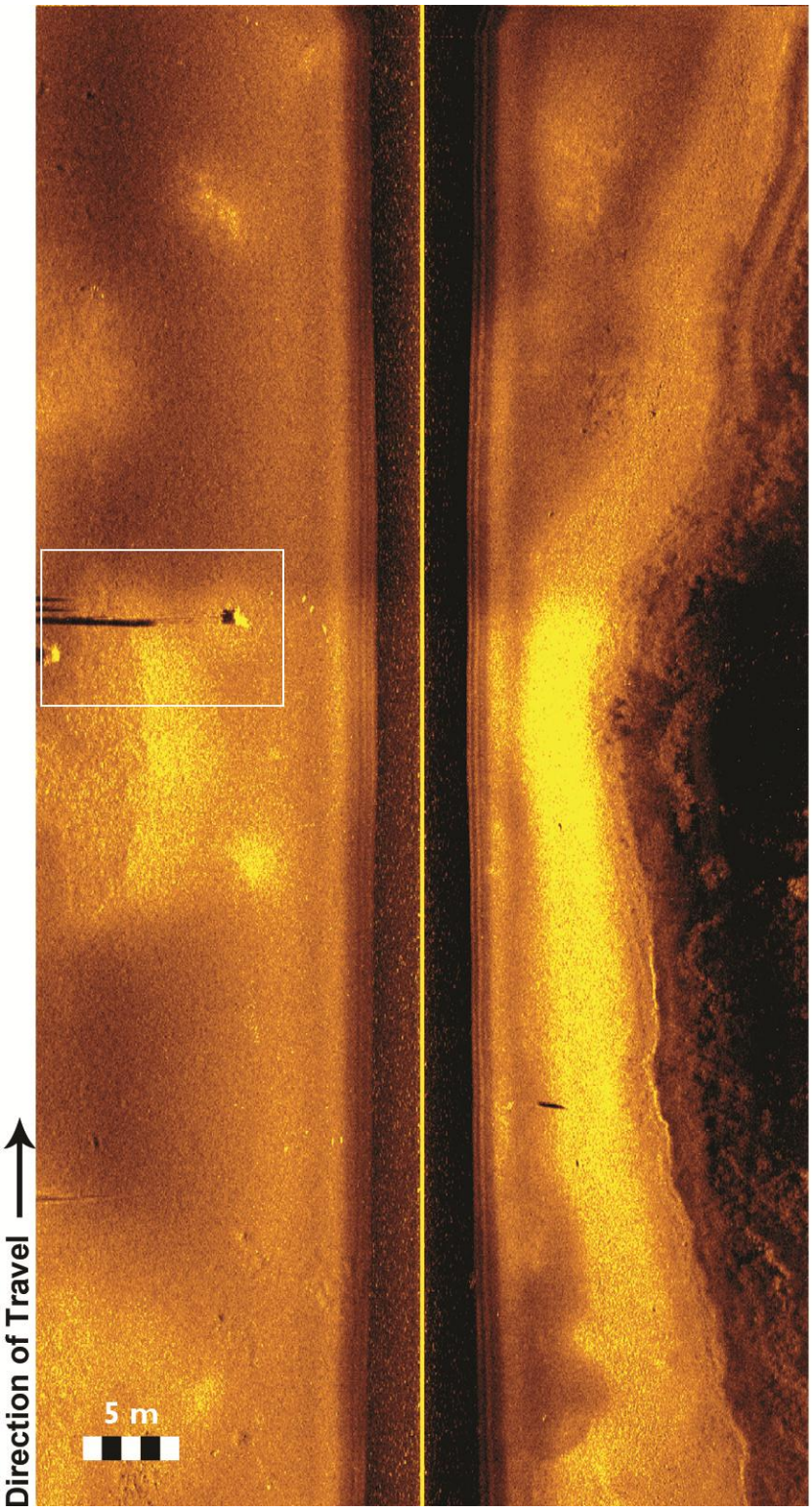

Figure 127: File 28Feb005, 900 kHz, 20 m, signals transmitted out of both sides of the towfish, Pig carcass detected and scored as "good."

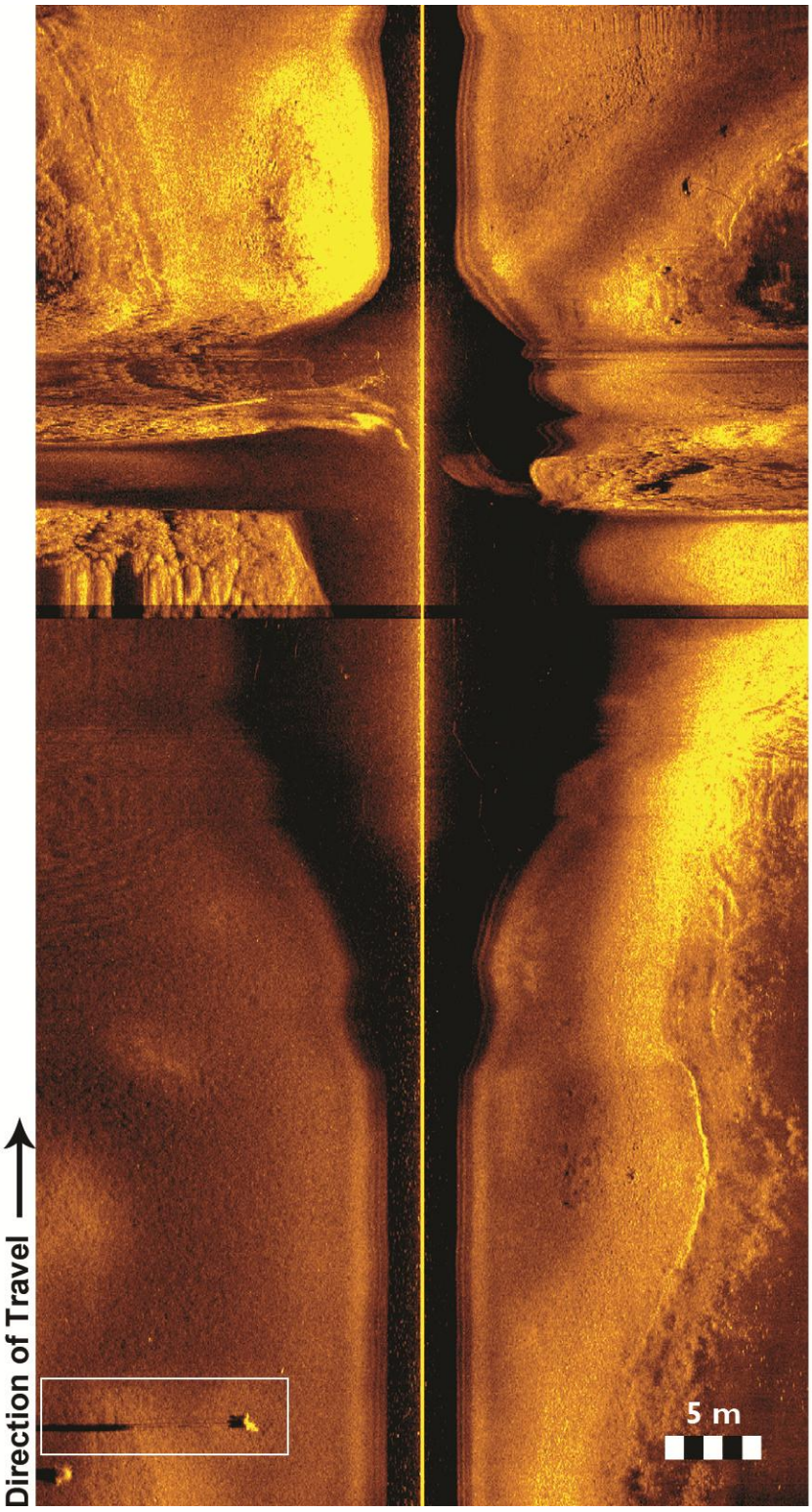

Figure 128: File 28Feb013, 1800 kHz, 20 m, signals transmitted out of both sides the towfish. Pig carcass detected and scored as "good."

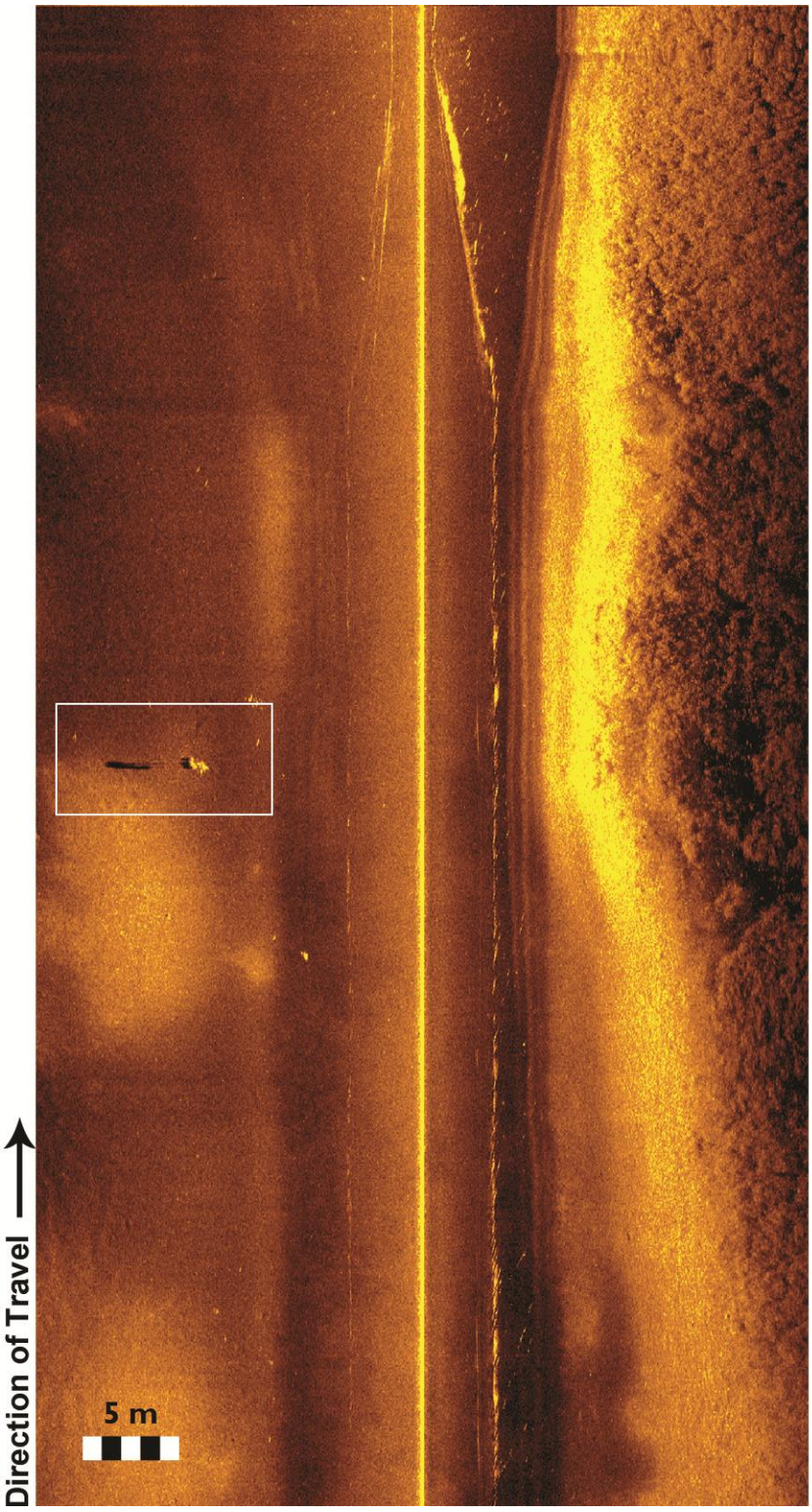

Figure 129: File 06Mar013, 900 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass detected and scored as "good."

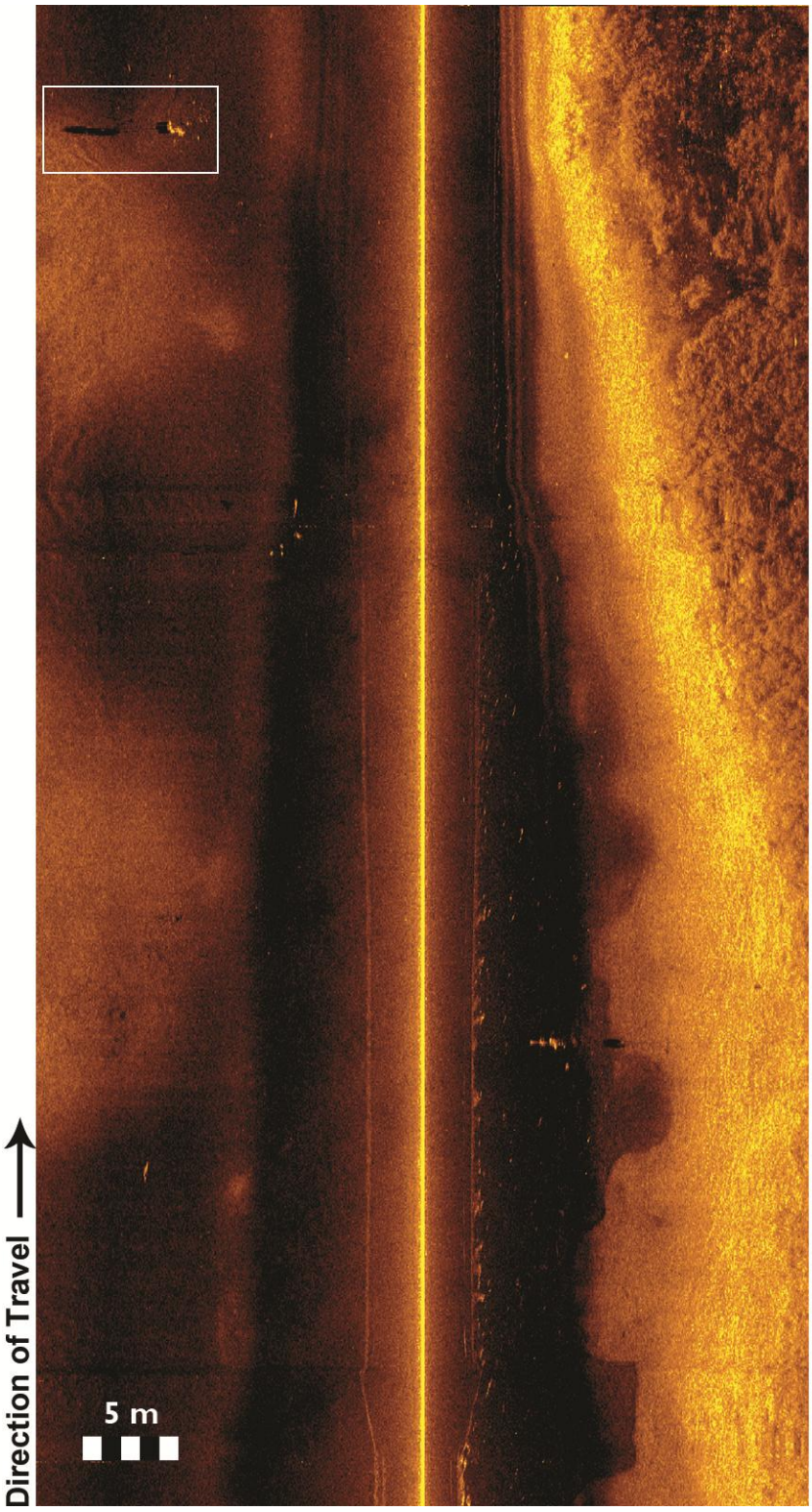

Figure 130: File 06Mar006, 1800 kHz, 20 m, signals transmitted out of both sides of the towfish. Pig carcass [top] detected and scored as "good."

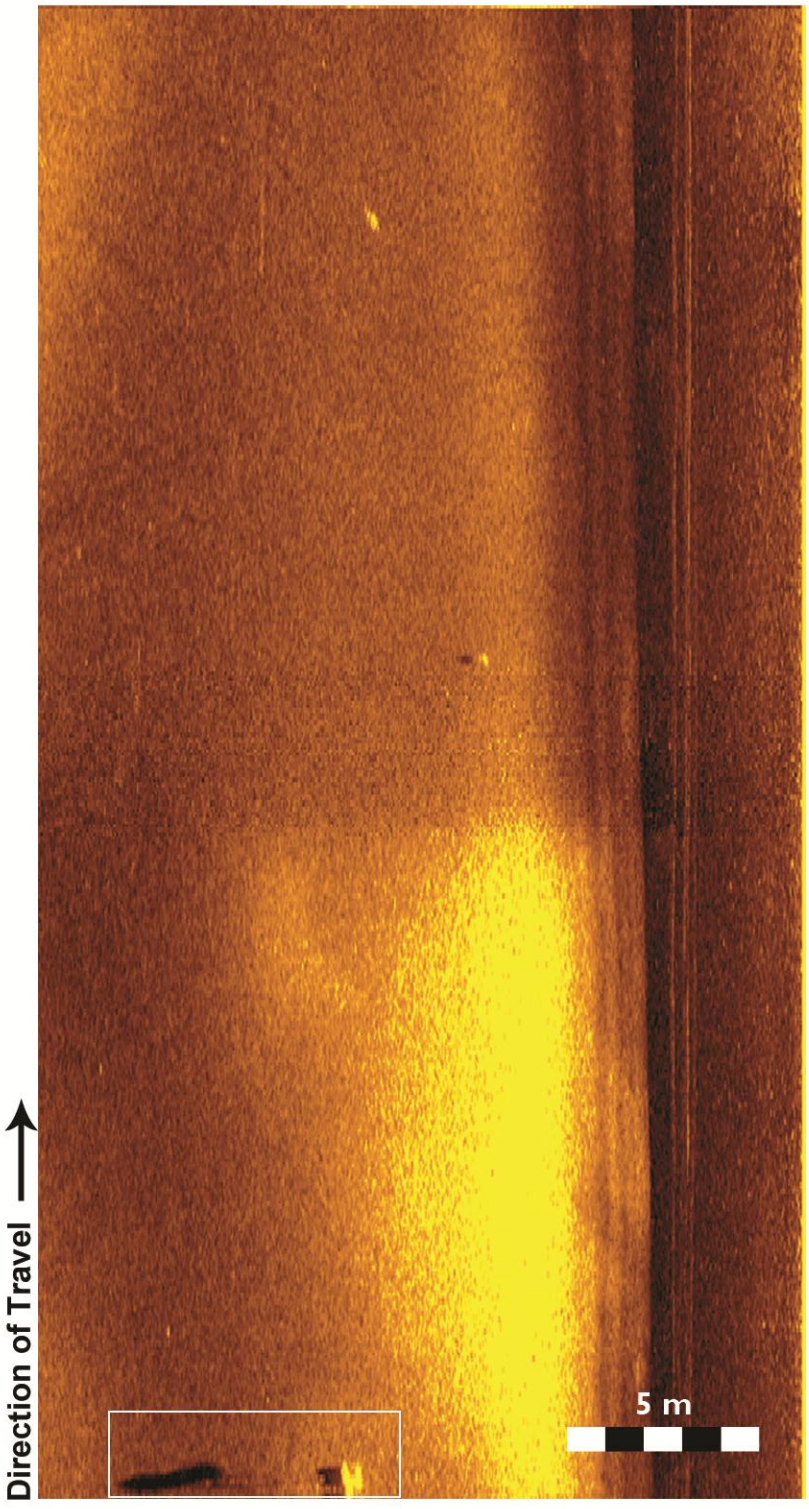

Figure 131: File 19Mar006, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

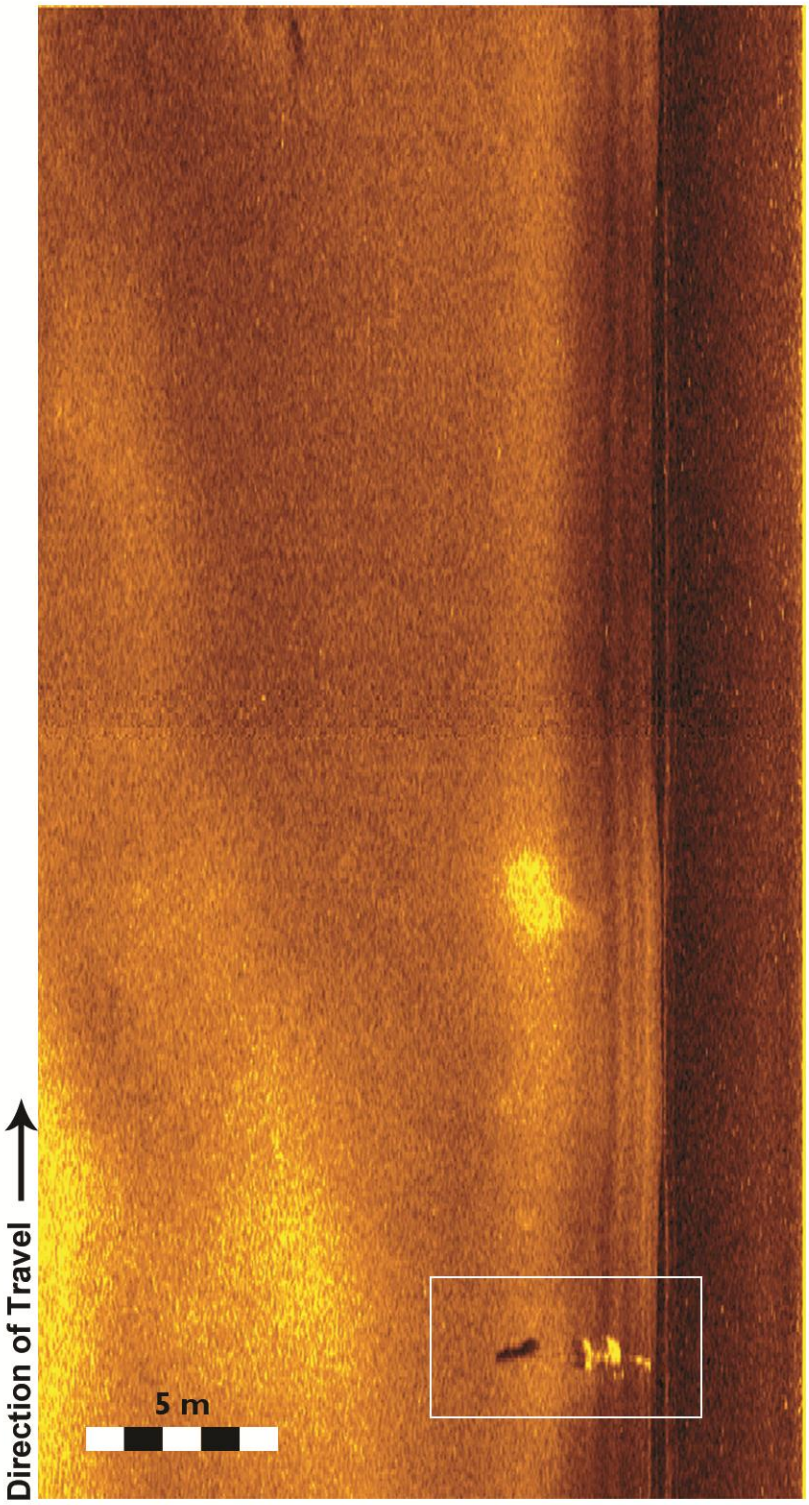

Figure 132: File 19Mar039, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

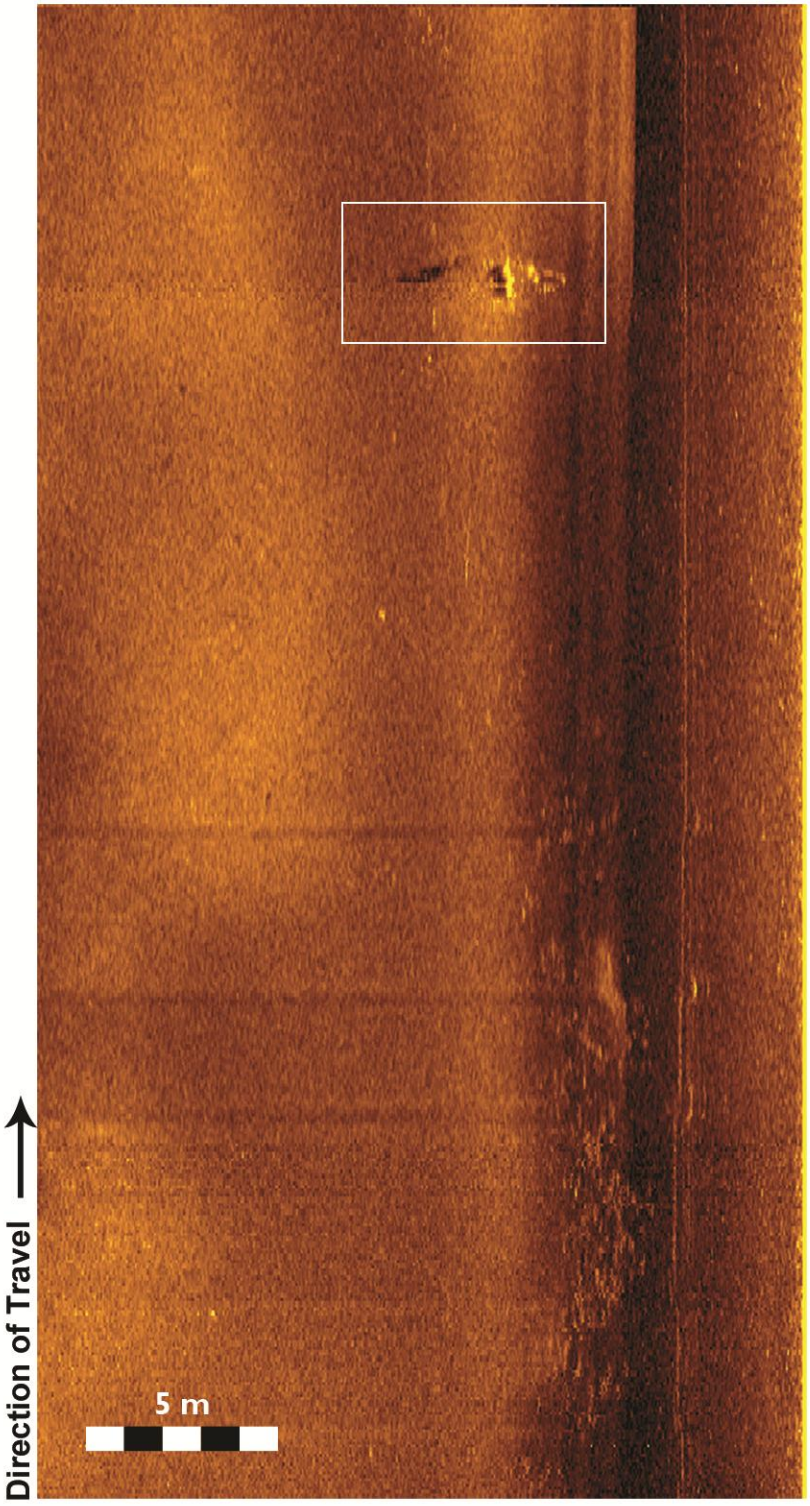

Figure 133: File 02Apr014, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

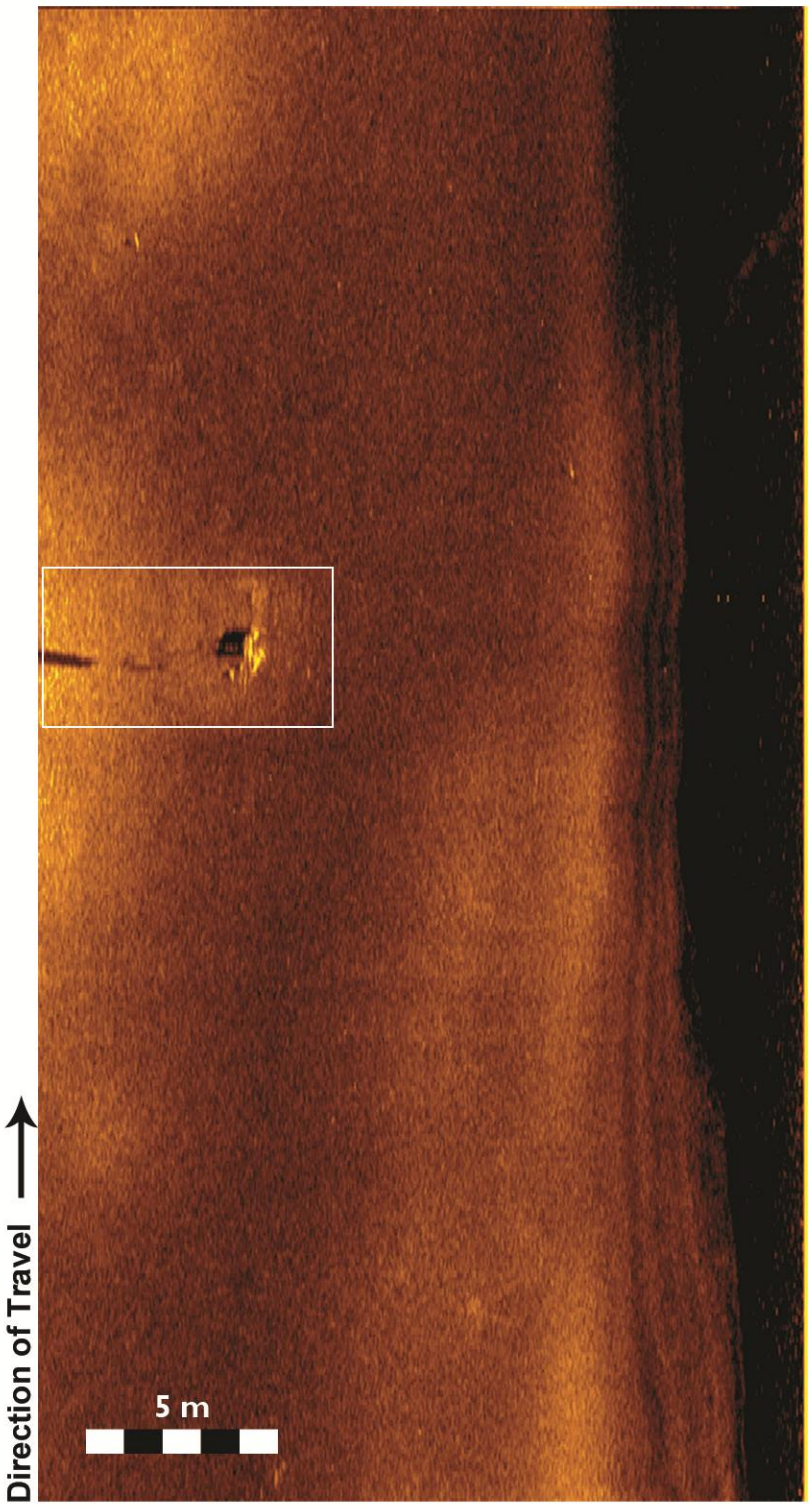

Figure 134: File 02Apr026, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "good."

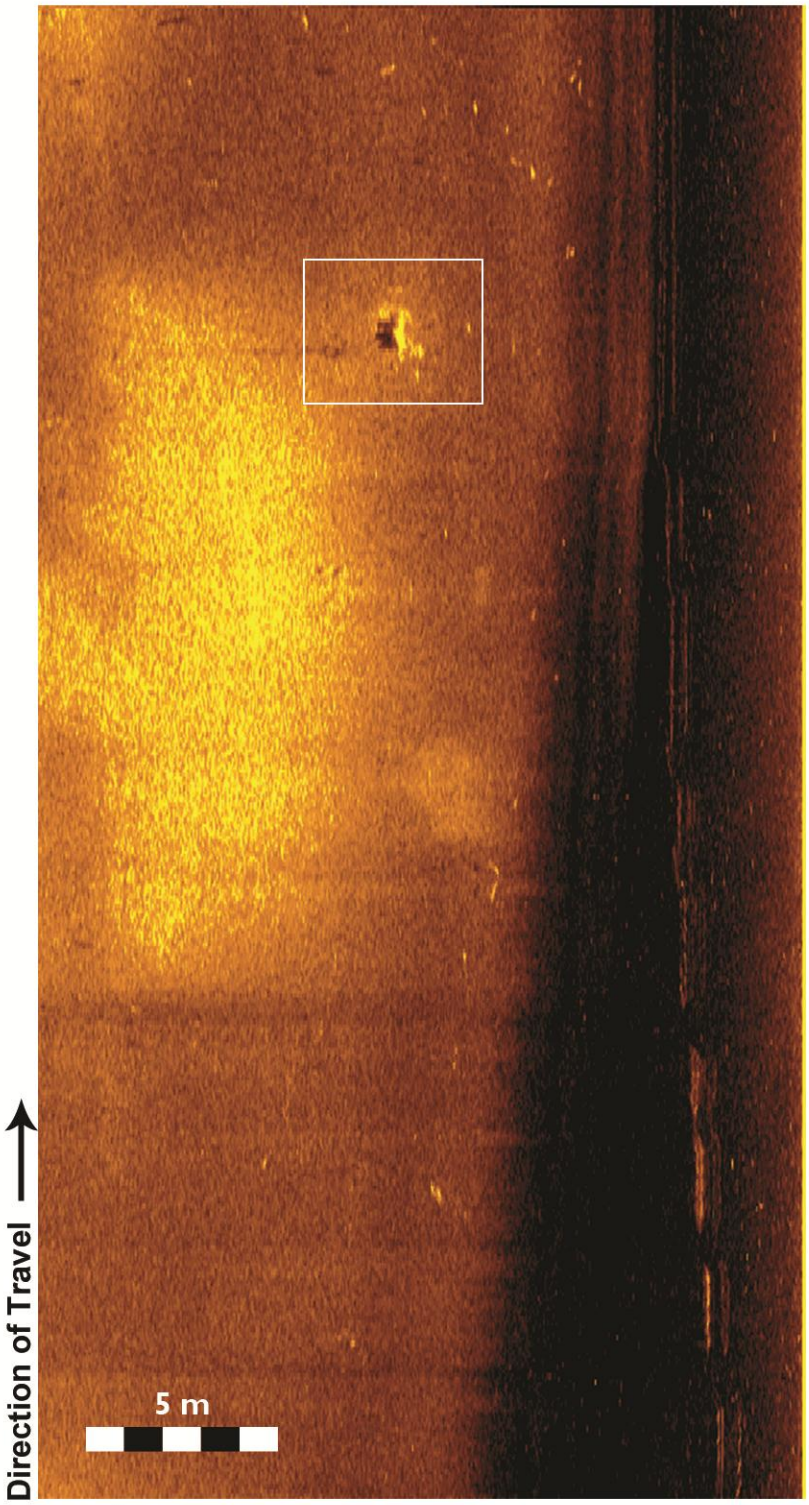

Figure 135: File 17Apr009, 900 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

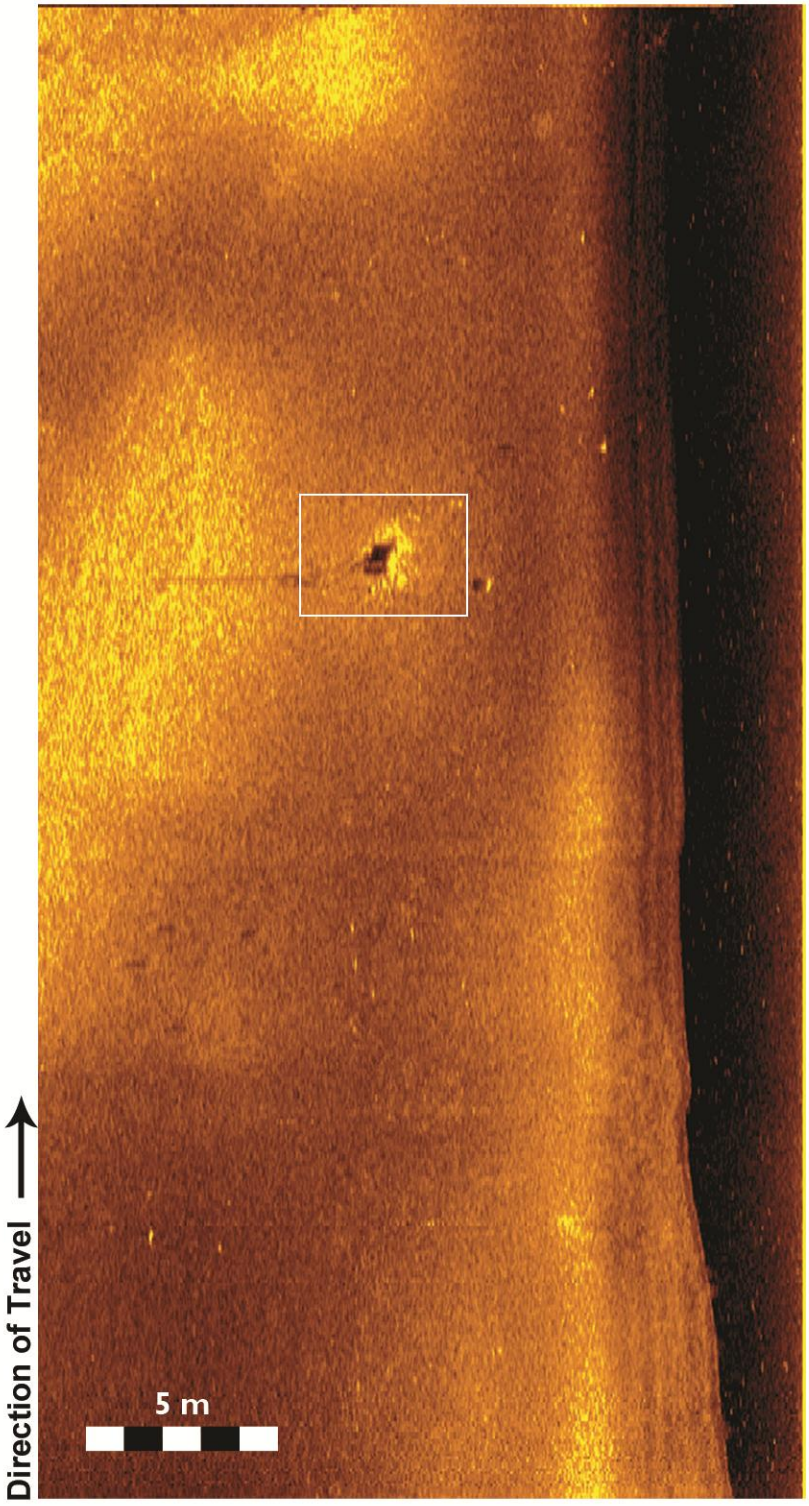

Figure 136: File 17Apr024, 1800 kHz, 20 m, signals transmitted out of the left side of the towfish. Pig carcass detected and scored as "poor."

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