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Seeing in the dark: A review of the use of side-scan sonar to detect and study manatees, with an emphasis on Latin America

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Abstract

Manatees are aquatic mammals that live in a variety of environments. Many of those shallow water environments have murky water, making detection using traditional visual surveys very challenging. Side-scan sonar was first proposed as a tool to detect and study manatees in these complicated habitats in 2005. Here, we summarize the use of this tool from 2005 to 2022 by searching the available literature. Our literature search revealed that this tool is being widely used in more than 20 locations and over 15 countries. All three manatee species are being studied with side-scan sonar. It is most useful in murky freshwater habitats that are not too deep or open (*e.g.*, large lagoons or lakes), where visual surveys are not effective. Most studies used side-scan sonar in combination with other methodologies such as passive acoustics and indirect evidence. Work is still needed to standardize the use of this technique so that image interpretation can be reliable, and results can be compared between studies. However, most studies indicated that this tool is essential in murky water habitats and provides one of the best ways to detect and study manatees.

Keywords:
Trichechus, Amazonian manatee, West Indian manatee, Antillean manatee, African manatee, survey methodology

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Introduction

Manatees (*Trichechus* spp.), along with dugongs, are fully aquatic mammals belonging to the order Sirenia, that are more closely related to hyraxes and elephants than they are to other marine mammals such as cetaceans and pinnipeds (Kellogg et al., 2007; Moore et al., 2021). Manatees are currently divided into three species and occur mostly allopatrically on both sides of the tropical and subtropical Atlantic Ocean (Reynolds et al., 2018). The West Indian manatee (*T. manatus*) is divided into two subspecies that occupy different geographical areas. The Florida subspecies (*T. m. latirostris*) occurs in rivers and coastal areas of the southeastern United States, while the Antillean subspecies (*T. m. manatus*) occurs in the major islands of the Caribbean and rivers and coastal areas of the Atlantic Ocean of Mexico, Central, and South America (Reynolds et al., 2018). Amazonian manatees (*T. inunguis*) are restricted to freshwater habitats in the Amazon Basin, and African manatees (*T. senegalensis*) are found along rivers and coast of west Africa from Senegal to Angola (Reynolds et al., 2018).

Manatees are very challenging to study in the wild due to their elusive nature. Unlike pinnipeds manatees never leave the water, and unlike cetaceans, manatees only momentarily expose a small portion of the rostrum when they surface to breath. Other than during winter in the northern extent of their range (*i.e.*, Florida), they rarely aggregate in large numbers. In addition, in areas where they have been hunted, they appear to modify their activity patterns to avoid locations and times of day when humans are most active (Rathbun et al., 1983; Gonzalez-Socoloske et al., 2011). Finally, most of lakes, rivers and estuaries used by manatees are murky (either turbid or tannin-stained). This low water visibility makes it very difficult to detect manatees in the wild using visual surveys (Aragones et al., 2012; Odewumi et al., 2017).

Due to these difficulties, sirenian biologists have had to use indirect indicators of manatee presence like feeding signs on vegetation or fecal samples (all of which have limitations) or develop new methodologies as an alternative to visual observation (Kikuchi et al., 2014; Hunter et al., 2018; Merchan et al., 2019; Ramos et al., 2020). One such methodology is the use of active acoustics in the form of side-scan sonar to aid in the detection of manatees (Gonzalez-Socoloske et al., 2009).

Side-scan sonar technology

Side-scan sonar is a type of sonar that uses a narrow lateral beam emitted on each side of the transducer, perpendicular to the direction of travel, to create an image of the bottom substrate. This type of sonar was developed in the late 1940s by the US military to scan and search large areas of the sea floor (Flemming, 1976). Military side-scan sonars were made in the 1950s and commercial units were developed in the 1960s after declassification of the original patent in 1958 (Flemming, 1976). Early systems would create the acoustic image on printed paper and since the 1980s the images have been produced digitally where they can be saved and viewed later (Sternlicht, 2017). In the mid 2000s, several companies incorporated this technology into consumer fishfinders. This redesign greatly reduced the cost of these units and changed the traditional deployment of the transducers from a submersible tow to being attached to the rear of the boat. This allowed the technology to be used in much shallower waters without fear of entanglement (Kaeser & Litts, 2010; Kaeser et al., 2012).

To create an acoustic image of the bottom surface and the water column the transducer must travel in a straight line at a constant speed. As the boat moves forward, one horizontal line of the image is added at a time to create the image. The image produced can be understood as a bird's-eye view of the habitat with the initial water column below the transducer seen as a dark band on each side of the image followed by a lighter section representing the bottom substrate. Objects on the substrate or above it will reflect the sonar beams based on their relative density and ability to block the beam and appear lighter shades. Behind the objects a characteristic shadow will be visible taking the shape of the object that is blocking the sonar beam. It is these shadows that give us the best indication of the shape of the objects.

Manatee detection with side-scan sonar

Since the 1980s there have been attempts to use sonar to detect manatees with mixed success (Dickerson et al., 1996; Bowles et al., 2004). These early attempts focused on using a variety of echo sounders (down-facing sonars). In 2004, a consumer grade side-scan sonar was tested to detect manatees in Honduras (Gonzalez-Socoloske et al., 2005; Gonzalez-Socoloske, 2007). It was subsequently tested in two other locations (Tabasco, Mexico and Crystal River, Florida) where manatees could be independently detected to develop detection rates (Gonzalez-Socoloske et al., 2009). Gonzalez-Socoloske et al. (2009) demonstrated that manatees could be detected successfully using side-scan sonar and that detection rates ranged from 81-93% at those initial locations. Based on the initial work in Honduras, Florida, and Mexico, Gonzalez-Socoloske and Olivera-Gomez (2012) identified a variety of applications that they envisioned the technology could be used for, including confirmation of mother-calf pairs, assistance in confirming detections, determining group size, assistance in captures, and benthic habitat characterization (Gonzalez-Socoloske & Olivera-Gomez, 2012). These initial experiments resulted in the now established methodology that has been used in a variety of habitats in more than a dozen countries. However, there has been no synthesis of this information to date and for the methodology to continue to improve and be more widely used it is important to understand what has been done successfully and what the limitations are.

In this review, we take a critical look at the use of side-scan sonar as a methodology to detect and study manatees by examining the literature from 2005 to 2022. Because Latin America is home to two of the three species of manatees, and most of the range of the West Indian manatee, it is expected that most of the work using this technique will be focused there. Based on the literature results we will 1) provide a general overview of the literature in terms of manatee species studied, countries of study, and type of publication; 2) evaluate the specific applications that side-scan sonar has been used for to study wild manatees; 3) assess what types of habitats it has been successfully deployed in, and; 4) discuss possible sources of error, the need to standardize the use for comparative studies, and future directions of study, including the use of other kinds of sonar.

Methods

To assess the impact of this methodology we conducted an extensive literature search for any peer-reviewed article, book, book chapter, report, thesis (BSc, MSc, PhD), and conference abstract that mentioned the use of side-scan sonar in relation to manatee research between 2005 and 2022. We searched for keywords in English, however literature in other languages was included if it resulted from the search. We searched conference abstract books if they were available online or we had access to a copy. Conference searches primarily focused on meetings of the Society of Marine Mammalogy (SMM), the Latin American Society of Speacialists in Aquatic Mammals (SOLAMAC), the Mexican Society of Marine Mammalogy (SOMMEMA), and the Mesoamerican Society for Biology and Conservation (SMBC). For all descriptive analyses (*i.e.* count totals, percentages) except for the type of publication, we excluded conference presentations, reports, and theses that were also published in peer-reviewed articles to avoid duplication of counts. We excluded secondary literature (books and book chapters) from the analysis as well, because they also summarized what was already published. To analyze the relationship between the number of contributions and year we used a Pearson's correlation coefficient.

Results

General overview of the literature

The literature search resulted in 86 publications indicating the use of this methodology to conduct research on manatees between 2005 and 2022. Of those, 32 were conference presentations, 26 peer-reviewed articles, 16 theses, eight books/book chapters, and four unpublished reports (Table 1; see Supplementary Material 1 for full list). The number of contributions has been steadily increasing (Pearson's r = 0.620, p = 0.006, df = 16, R^2 = 0.385), as has the cumulative number of countries it is being utilized in (Fig. 1). Projects have been carried out in 15 countries, mostly in Latin America (87.5%). Most of the work has been done in Mexico (36.0%), with the rest of the countries each representing less than 10% of the publications (Table 1). After the removal of duplicates (conference presentations, reports and theses that were also published in peer-review journals, as well as books and book chapters that are secondary literature), 44 publications were left. Most of the publications dealt with *T. m. manatus* (77.3%), while 11.4% dealt with *T. senegalensis*, 9.1% with *T. inunguis*, and only 2.3% with *T. m. latirostris* (Fig. 1; Fig. 2A, D, G). Several side-scan sonar units have been used (Humminbird®, Fig. 2A, B, E, F, H; Garmin®, Fig. 2C, D; Lowrance®, YellowFin®), but most of the work has been done using Humminbird® units (80.0%) proposed in the original study by Gonzalez-Socoloske et al. (2009).

Applications for technology

The applications of study using side-scan sonar varied but were most applied to manatee detection (24.1%), abundance estimates (18.5%), presence/absence (14.8%), habitat characterization (14.8%), and distribution (13.0%). Other applications included habitat use, encounter rate, density, and community involvement (Table 1).

Types of habitats where it has been effective

Side-scan sonar has been used in a variety of habitat types including coastal/marine (Fig. 2E), estuarine (brackish water; Fig. 2H), and freshwater tannin-stained (Fig. 2A, C, D, F), clearwater (Fig. 2B) and turbid (Fig. 2G) river and lake environments, however most of the publications dealt with freshwater habitats (85.7%), of which tannin-stained freshwater habitat (50.6%) and freshwater turbid habitat (29.9%) make up the lion's share (Fig. 1). A substantial portion of the papers dealt with seasonally dynamic wetlands (flooding forests and marshes).

Table 1. Descriptive statistics of publications 2005 - 2022 that mention the use of side-scan sonar in relation to manatee research.

Publication Type	Count	Percent
Conference presentation	32	37.2%
Peer-reviewed article	26	30.2%
Theses (BSc, MSc, PhD)	16	18.6%
Book/book chapter	8	9.3%
Unpublished report	4	4.7%
Country of Study*	**Count (each country)**	**Percent (each country)**
Mexico	18	36.0%
Belize, Brazil, Cameroon, Costa Rica	4	8.0%
Panama	3	6.0%
Colombia, Ecuador, Guatemala, Peru	2	4.0%
Cuba, French Guyana, Honduras, Nigeria, USA	1	2.0%
Application of Side-scan Sonar*	**Count (each category)**	**Percent (each category)**
Detection	13	24.1%
Abundance	10	18.5%
Presence/Absence; Habitat Characterization	8	14.8%
Distribution	7	13.0%
Density; Encounter Rate	3	5.6%
Community Involvement; Habitat Use	1	1.9%

*The same study can have multiple countries and applications listed.

Discussion

General overview of the literature

It is likely that the list of reports and conference abstracts is incomplete and biases toward studies that we have participated in or have direct knowledge of due to the difficulty of getting older abstract books. Not surprisingly, the majority of the work has occurred in Mexico, because that is where the technique was first described and had the best results in the initial study (Gonzalez-Socoloske et al., 2009). However, it was surprising to see the number of unique locations (at least seven, including Catazajá wetlands in Chiapas, Alvarado Lagoon System in Veracruz, Laguna de las Ilusiones, Pantanos de Centla, and San Pedro River in Tabasco, Laguna de Terminos in Campeche, and Rio Hondo in Quintana Roo) and independent research groups (at least seven) within Mexico that are using the methodology (Rodas-Trejo et al., 2008; Gonzalez-Socoloske et al., 2009; Daniel-Rentería et al., 2012; Gonzalez-Socoloske & Olivera-Gomez, 2012; Jiménez-Domínguez & Olivera-Gómez, 2014; Acevedo-Olvera et al., 2015; Puc-Carrasco et al., 2016; Puc-Carrasco et al., 2017; Ramírez-Jiménez et al., 2017; Serrano et al., 2017; Ladrón de Guevara-Porras et al., 2019; Corona-Figueroa et al., 2021, 2022). The 15 countries with confirmed use of side-scan sonar are likely an underrepresentation of the overall number because there are some localities where it has been used, but they are yet to publish their results in any format that we were able to assess. For example, we are aware that it has also been used in the Demerara River, Guyana (Indranee Roopsind, University of Guyana, pers. comm., 31 August 2022) and Lake Lere, Chad (Aristide Takoukam Kamla, African Marine Mammal Conservation Organization, pers. comm., 29 August 2022). However, it is clear that more work could be done to expand the representation of use in other counties other than Mexico, especially in South America and Africa.

The differences observed between the number of side-scan sonar efforts studying directed at the different manatee taxa is more likely explained by the number of research groups studying them and the variety of habitats and range of the different taxonomic groups. Antillean manatees are being studied in over a dozen countries from Mexico to Brazil and the Greater Antilles and much of their habitat consists of dark water rivers and lakes (Self-Sullivan & Mignucci-Giannoni, 2012; Castelblanco-Martínez et al., 2013; Arévalo-González et al., 2014; Gonzalez-Socoloske et al., 2015; Alvarez-Alemán et al., 2017; Serrano et al., 2017; Reynolds III et al., 2018; Corona-Figueroa et al., 2021; Deutsch et al., 2022; Marsh, 2022), so it was expected that most of the studies using side-scan sonar have focused on that subspecies. African and Amazonian manatees also use dark water habitats, but there are fewer research groups studying them. Nevertheless,

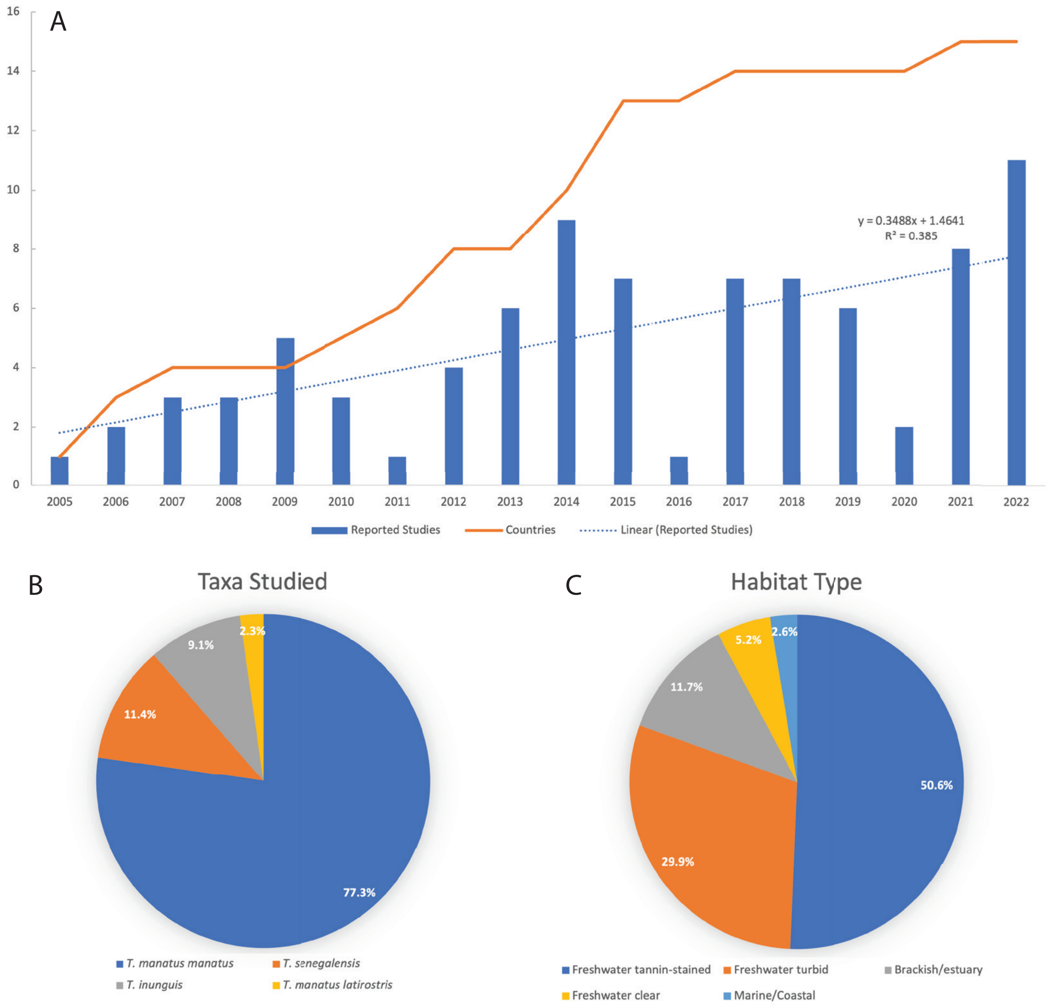

Figure 1. A) Cumulative number of countries by year (orange) and the yearly number of studies (blue) that mention side-scan sonar to study manatees. Linear trend (blue dashed line); B) Proportion of manatee taxa and C) habitat type studied using side-scan sonar.

both those taxa had significant representation in the side-scan sonar literature, and we expect that percentage to grow in the coming years. The Florida manatee was the least represented, likely because of the possibility to count them during the cold winter months at the known aggregation sites (Garrott et al., 1994; Reynolds & Wilcox, 1994; Ackerman, 1995; Reep & Bonde, 2021). This advantage in Florida negates the need to seek an alternative form of manatee detection.

Most of the studies used Humminbird® sonar units, probably because the initial studies used this brand, however a few have used alternative brands. As more companies provide financially accessible units, this diversity is likely to grow. Most units used frequencies above 200 kHz, which should be well above the detection threshold of manatee hearing and sensation of post cranial vibrissae (Gerstein et al., 1999; Reep et al., 2011), however some using lower frequencies (*i.e.* < 150 kHz) might be within what other sympatric species such as dolphins might detect (Houser & Finneran, 2006) and care should be taken when conducting studies in those locations.

Applications for technology

Side-scan sonar has mostly been used to study manatee detection (Gonzalez-Socoloske et al., 2009; Gonzalez-Socoloske & Olivera-Gomez, 2012; Castelblanco-Martínez et al., 2018; 2019; Raoult et al., 2020 ; Corona-Figueroa et al., 2022), abundance (Arévalo-González et al., 2014; Puc-Carrasco et al., 2016; Choi-Lima, 2017; Guzman & Condit, 2017; Puc-Carrasco et al., 2017; Serrano et al., 2017; Corona-Figueroa et al., 2021), distribution (Rodas-Trejo et al. 2008; Daniel-Rentería et al. 2012; Espinoza Marin 2013; Arévalo-González et al. 2014; Callejas-Jiménez et al. 2021; Factheu et al. 2022), and presence/absence (Rodas-Trejo et al., 2008; Gonzalez-Socoloske et al., 2009; Jiménez-Domínguez & Olivera-Gómez, 2014; Acevedo-Olvera et al., 2015). Some studies have employed distance sampling methods (Buckland et al., 2001) to calculate abundance and density (Arévalo-González et al., 2014; Guzman & Condit, 2017; Serrano et al., 2017; Narváez Ruano et al., 2021), however there is yet no standard application. Castelblanco-Martinez et al. (2018) calculated encounter rate based on the number of manatee detections per hour of survey, while Puc-Carrasco et al. (2016) and Narváez Ruano et al. (2021) calculated encounter rate based on the number of detections per 10 km of survey, likely due to the low number of detections. Puc-Carrasco et al. (2016) applied a correction factor taking advantage of a scanned area with a known number of manatees. They found that they missed about 20% of the manatees available for detection (which would imply a detection rate of 80%, similar

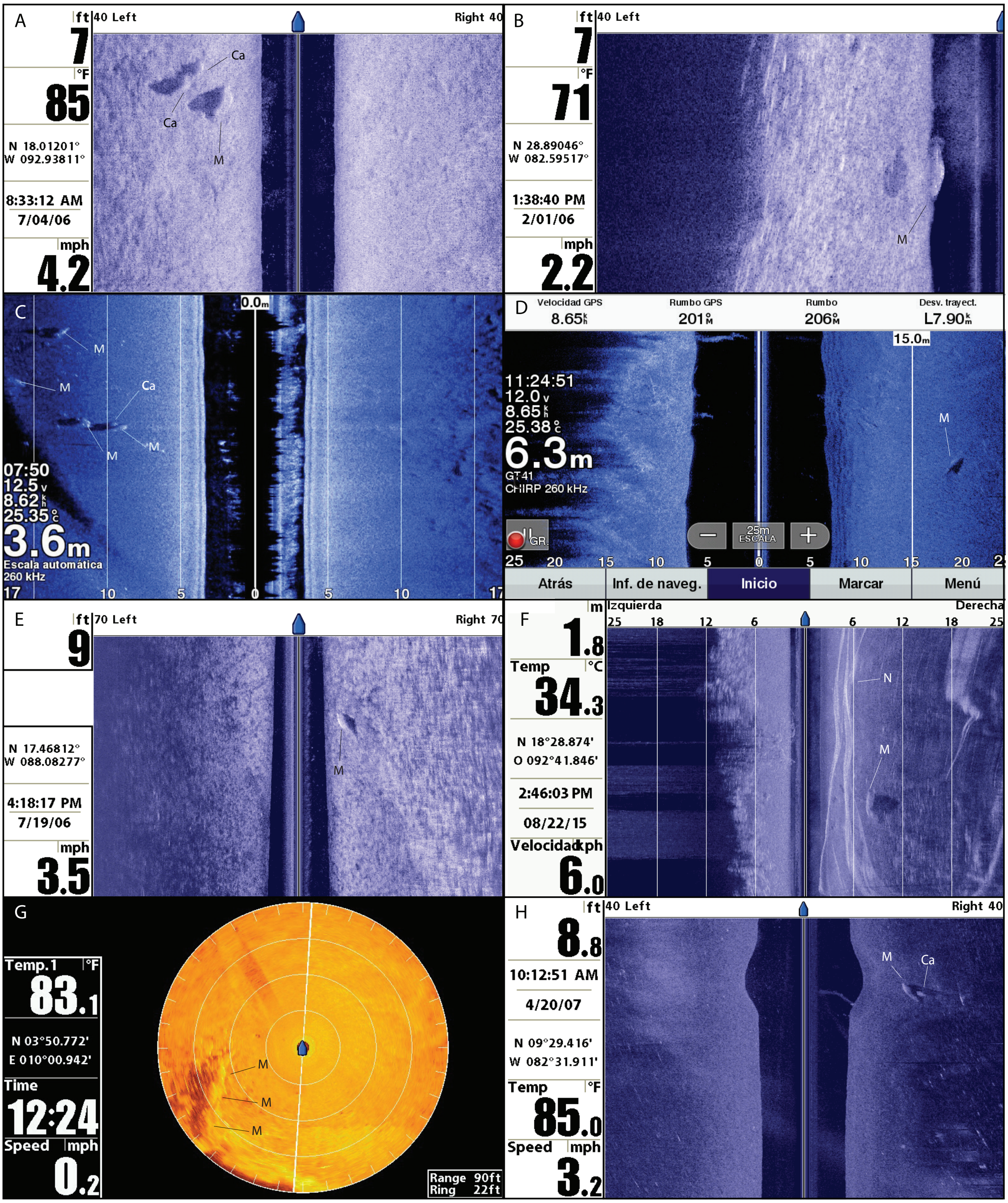

Figure 2. Examples of side-scan sonar images of manatees. M = adult manatee, Ca = calf, N = net. A) Adult Antillean manatee (*Trichechus manatus manatus*) with two calves in a tannin-stained freshwater lake. Laguna de las Ilusiones, Tabasco, Mexico. Humminbird system. Image by D. Gonzalez-Socoloske; B) Adult Florida manatee (*T. m. latirostris*) in a freshwater clearwater river. Crystal River, Florida, USA. Humminbird system. Image by D. Gonzalez-Socoloske; C) Group of four adult Antillean manatees and one calf in a freshwater tannin-stained river. Rio Hondo, Quintana Roo, Mexico. Garmin system. Image by M. Fabiola Corona-Figueroa; D) Adult Amazonian manatee (*T. inunguis*) in a freshwater tannin-stained river. Rio Yungas, Loreto, Peru. Image by Sarah Landeo; E) Adult Antillean manatee in the marine coastal habitat (seagrass beds). Drowned Cayes, Belize. Humminbird system. Image by D. Gonzalez-Socoloske; F) Adult Antillean manatee surrounded by a capture net in a tannin-stained freshwater water course. El Coco stream, Tabasco, Mexico. Humminbird system. Image by L. D. Olivera-Gomez; G) Three adult African manatees (*T. senegalensis*) in a turbid freshwater lake. Lake Ossa, Littoral Region, Cameroon. Humminbird 360-degree system. Image by Aristide T. Kamla; H) Adult Antillean manatee and calf in a brackish river mouth. Rio San San. Bocas del Toro, Panama. Humminbird system. Image by D. Gonzalez-Socoloske.

to what was initially reported by Gonzalez-Socoloske et al., 2009). Most studies do not account for a detection probability because of the impossibility of knowing the true number of manatees in the area in the first place.

One notable result of using side-scan sonar has been the ability to calculate abundance and relative abundance in locations where it was not possible before, such as seasonally flooding wetlands of the Usumacinta-Grijalva Basin in Tabasco, and the Alvarado Lagoon System in Veracruz, both in Mexico. These freshwater systems are thought to contain the vast majority of the estimated 1,000-2,000 manatees in Mexico (Deutsch et al., 2008; UNEP, 2010). However, based on all available field studies using side-scan sonar (Daniel-Rentería et al., 2012; Jiménez-Domínguez & Olivera-Gómez, 2014; Puc-Carrasco et al., 2016; Serrano et al., 2017), these previous estimates appear to be grossly overestimated and misrepresent the urgency of the status of Antillean manatees in Mexico and the entire range (since Mexico is thought to have the largest population).

Several projects have used the side-scan methodology to study manatee habitat. While not directly used to detect manatees, side-scan sonar has been used in Cuba, Panama, and Mexico to generate bathymetric maps (Jiménez-Domínguez & Olivera-Gómez, 2014; Guzman & Condit, 2017; McLarty et al., 2020). In Cuba, McLarty et al. (2020) used side-scan mosaic data to characterize the benthic habitat of coastal lagoons in the Isla de la Juventud, providing an invaluable tool to manatee researchers interested in habitat use. In addition, side-scan sonar systems have been used to create surface temperature maps (taking advantage that the transducers have built-in thermometers) in Tabasco, Mexico (Jiménez-Domínguez & Olivera-Gómez, 2014), as an aid in characterizing manatee resting holes in the Drowned Keys of Belize (Bacchus et al., 2009), and as a mapping tool for submerged aquatic vegetation in Lake Ossa, Cameroon (Takoukam et al., 2021). Ladrón de Guevara-Porras et al. (2019) even used side-scan sonar as a tool to involve the local community in the Terminos Lagoon system of Campeche, Mexico.

Apart from manatees, side-scan sonar units have been useful to study a variety of other aquatic fauna including sturgeon (Flowers & Hightower, 2013, 2015), large turtles (Davy & Fenton, 2013), sawfish (Papastamatiou et al., 2020), and dolphins (Gonzalez-Socoloske et al., 2019; Schneider & Zhuang, 2020).

Types of habitats where side-scan sonar has been effective

The most common habitat where the side-scan sonar methodology has been applied has been freshwater systems that are tannin-stained or turbid (Brice, 2014; Vargas Ramírez, 2015; Castelblanco-Martínez et al., 2018; Corona-Figueroa et al., 2021; Narváez Ruano et al., 2021; Puc-Carrasco, 2021). These habitats are some of the most difficult to detect manatees through visual observation and usually lack substantial underwater vegetation due to the low light penetration. These two facets make them the ideal locations to use side-scan sonar, and they provide the most definitive images produced by the methodology. In addition, many studies have indicated that in seasonally flooding systems (*e.g.* Alvarado Lagoon System, Usumacinta-Grijalva Basin, Orinoco Basin, Sanaga River Basin, Amazon River Basin), the dry season provides the best opportunities to use the technology due to the concentration of the manatees and the shallow water (Arévalo-González et al., 2014; Jiménez-Domínguez & Olivera-Gómez, 2014; Ramírez-Jiménez et al., 2017).

Side-scan sonar has been used successfully in clear freshwater systems (Bacchus, 2007; Gonzalez-Socoloske et al., 2009) (Fig. 2B), however these areas can be more efficiently surveyed using drones, aerial surveys or visual boat surveys (Raoult et al., 2020), so it is not surprising that few studies have invested in conducting sonar surveys that potentially require more time and effort and might yield fewer detections. Interestingly, no study to our knowledge has attempted to conduct side-scan surveys at night even though it has been reported that manatees will travel and forage at night (Montgomery et al., 1981; Rathbun et al., 1983; Jiménez, 1999; Akoi, 2004; Carvalho, 2013; Ponnampalam et al., 2022).

In Mexico, side-scan sonar has been used to detect manatees to aid in scientific captures intended for tagging or health projects (Morales-López et al., 2012; Aragón-Martínez et al., 2014; Olivera-Gómez et al., 2021). In Tabasco, Mexico manatees are captured by encircling them with a net. Repeated sonar scans of encircled manatees documented that manatees are able to escape from nets on most capture attempts, especially in zones where nets are heavily used (Fig. 2F). Both thicker silk nets as well as thinner monofilament nets are visible using side-scan sonar, making it possible to use as a tool to monitor artisanal and/or illegal fishing along water bodies.

Sources of error, the need to standardize, and future directions of study

Sources of Error

Perception biases

There are several possible sources of error when interpreting data from side-scan sonar. We discussed possible perception bias and availability bias in our previous paper (Gonzalez-Socoloske & Olivera-Gomez, 2012). Perception bias can occur in two forms: false negatives (where a manatee is scanned, but the observer fails to identify it) and false positives (where an object is identified as a manatee, when in fact it is not). Both can affect manatee estimates and should be carefully assessed. False positives can be avoided by having independent experienced observers who evaluate the images or recordings *ex situ* or *in situ* as has been done by several studies (Castelblanco-Martínez et al., 2018; Corona-Figueroa et al., 2021) and by conducting a second or third pass when a manatee detection is made (Puc-Carrasco et al., 2017). False negatives can also be partially dealt with by having multiple independent observers. Puc-Carrasco et al. (2016) and Corona-Figueroa et al. (2021) noted that user experience was important.

Availability biases

Availability bias (Marsh & Sinclair, 1989) occurs when a manatee is present, but the observer is not able to detect it because it is out of his range of view (or is undetectable with the method being used). This type of bias is more difficult to control because it requires knowledge about the detection rate of the methodology in that particular environment in both time and space. This can only really be done when the number of manatees in the closed area is known, or if in the area there is a known number of tagged and/or easily identifiable individuals. Due to the complexity of this, availability bias remains a difficult problem for most locations where side-scan sonar is most effective. Many studies have increased the probability of detection (and decreased availability bias) by using a combination of detection methods simultaneously (Rodas-Trejo et al., 2008; Puc-Carrasco et al., 2017; Serrano et al., 2017; Callejas-Jiménez et al., 2021; Corona-Figueroa et al., 2021; Narváez Ruano et al., 2021). This involved using sonar along with other detection methods such as passive acoustics, visual surveys, and indirect evidence of presence (*e.g.*, fecal samples, feeding marks on aquatic vegetation).

Variable Manatee Behavior

Manatee behavior can be quite variable depending on the location, season, habitat configuration and time of day. In the Brazilian Amazon Basin, attempts to scan a radio-tagged wild Amazonian manatee were unsuccessful in 2017 (Gonzalez-Socoloske, pers. obs.). Every time the research boat approached, the manatee would displace in such a way that we could never be in a perpendicular position relative to the manatee and still be within the scanning range of the side-scan sonar. Similarly, Antillean manatees in urban lake of Laguna de las Ilusiones have apparently learned to avoid the survey boat after years of sinking to the bottom and remaining still (Olivera-Gomez, pers. obs.), making it much harder to detect them using the sonar. This could be because they are captured in the lake with the aid of sonar, and it is possible that they no longer feel they are undetectable like they previously were when they sank to the bottom and remained still. On several occasions the manatees have been observed to use underwater logs or shore vegetation to “hide” from the survey team (Olivera-Gomez, pers. obs.). Puc-Carrasco et al. (2016) noted a difference in avoidance behavior by manatees in narrow waterways and open areas. Manatees moved away from the transect line in narrow waterways and remained at the bottom in open areas (Puc-Carrasco et al., 2016). Those behaviors make it difficult to compare results between locations. Machuca Coronado (2015) reported that manatee detection in open habitats (large lakes or coastal areas) in Guatemala proved difficult because animals would displace before the boat could pass them perpendicularly (Machuca Coronado, 2015).

The Need for Standardization

Most studies employed an individual that had experience with side-scan sonar or used experts to help decipher the data after it was collected, however due to the potential effects of several variables (*e.g.*, habitat, manatee species, survey speed), it is important to standardize protocol for the interpretation of the images. This could be done by creating a large database of sonar images of manatees that scientists and managers could all have access to. In addition, it is recommended that methodologies for calculating abundance, relative abundance, encounter rate, and density also be standardized so that comparisons between locations or seasons is possible. One plausible solution is to employ artificial intelligence (machine learning) so that manatees can be automatically detected from side-scan sonar images and recordings (see Norouzzadeh et al., 2018; McClure et al., 2020). This must factor in several variables (*e.g.*, sonar used, speed of boat, water depth, sonar lateral range, benthic habitat type) that might have an effect on the algorithms detecting the manatee images. Images could be pooled from a variety of locations representing different habitats, manatee species, and benthic types to aid the algorithm.

Until there is a better understanding of the possible violations of the assumptions of Distance sampling (*i.e.* detecting the animal before it detects the observer and moves position relative to the boat), Distance sampling should be used with caution to calculate abundance and relative abundance, unless some correction factor is used to deal with any potential violation of the methods’ assumptions (Buckland et al., 2001).

Future directions of study

It is difficult to predict where manatee studies will go using sonar in the next 10 - 15 years. However, several other sonar variations might be useful to avoid some of the shortcomings of side-scan sonar. Humminbird® has produced a circulatory side-scan sonar since 2012 and it has been tested in a few locations (*e.g.*, Brazil, Cameroon; unpublished data). It operates the same way as linear side-scan sonar, only that the transducer remains stationary and the lateral sonar beams rotate 360 degrees (Fig. 2G), similar to how circular scanning radio detection and ranging (RADAR) works in air ("Radio detection and ranging," 1943). However, the image is harder to interpret and unlike regular linear side-scan sonar, it is not possible to analyze the recordings in a third-party software, which limits the results to screenshots. However, this stationary methodology allows for point scans that do not have the boat motor on and can be very important in areas where linear surveys are challenging or where manatees have learned to avoid boats.

Another potential direction of study is to use the sonar during night surveys to compare habitat use and distribution between nighttime and daytime. Finally, the use of other sonar types like dual imaging sonar (DIDSON) and multibeam sonar appears to be very promising (Martignac et al., 2014; Hastie et al., 2019; Gonzalez-Socoloske et al., 2022), although the much steeper cost ($15,000 - $50,000 USD) will likely make it unfeasible at a larger scale and for many groups working in developing countries.

Conclusion

Side-scan sonar is now an established tool that scientists are using in a variety of ways to study manatees (see secondary literature Aragones et al., 2012; Reep & Bonde, 2021; Deutsch et al., 2022; Marsh, 2022; O’Shea et al., 2022; Ponnampalam et al., 2022). It has been demonstrated to be useful in a variety of environments but is primarily important in murky freshwater systems and during the dry season in seasonally dynamic systems. The most common applications for the methodology are to study abundance, detection, presence/absence, and distribution, however there is lack of standardization, which limits comparing studies between locations. Current limitations for this methodology include feasibility in certain habitats (*e.g.* very complex substrates where distinguishing manatees can be challenging, deep water and open habitats), the need to be moving in a constant direction and speed, the possibility that manatees may move away from the sonar beam prior to contact with them (especially in large open habitats), and the lateral range of the sonar (currently about 30 m or so). Unknown and variable detection rates are also an unresolved problem that should be carefully thought about when designing studies. Despite these limitations, side-scan sonar has proven to be a valuable tool for scientists and conservationists working with these elusive animals, especially in locations where other conventional methods that require visual detection are not possible or yield very poor results.

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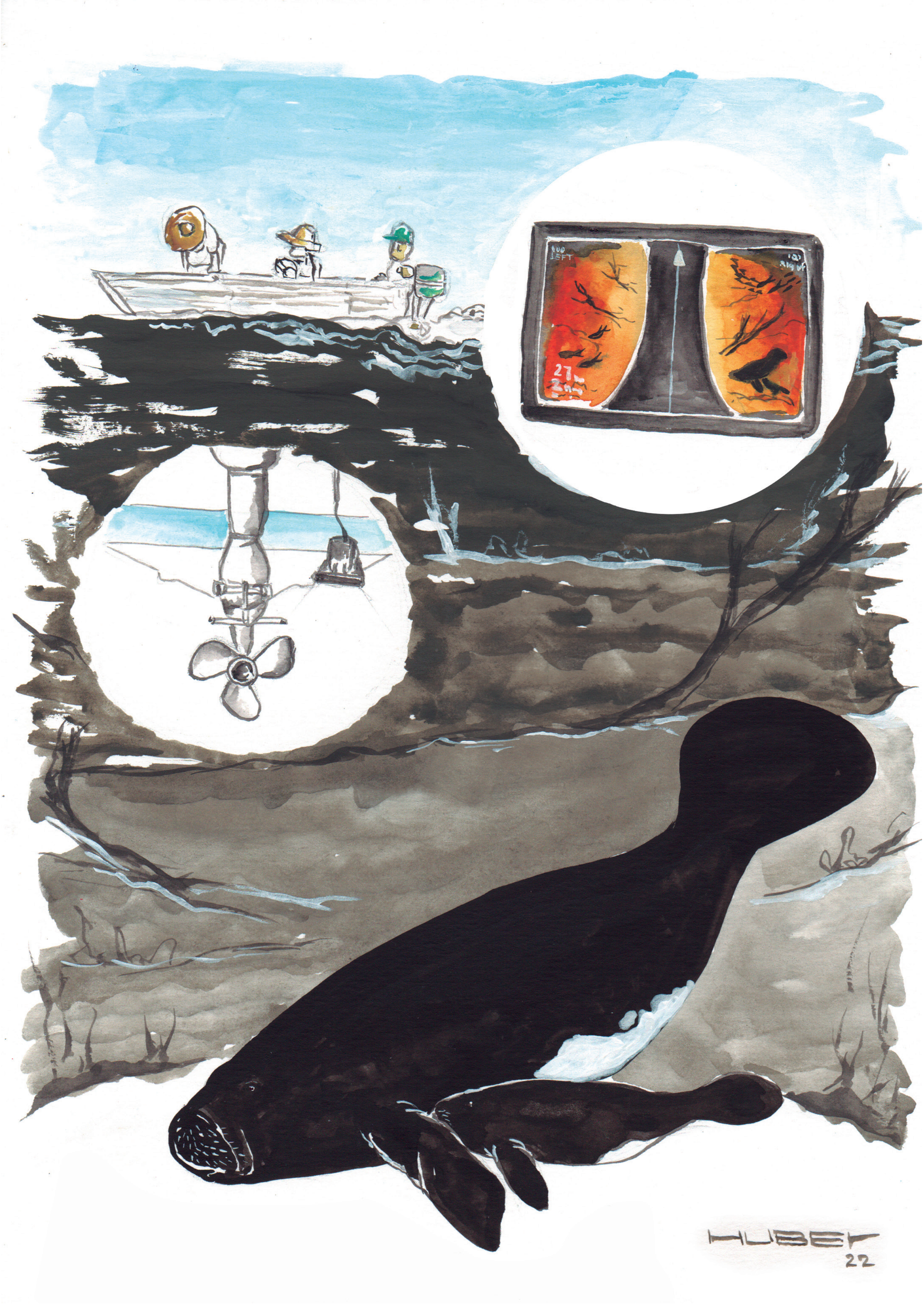
Supplementary material

Supplementary Material 1 - Database of scientific literature (2005-2022) related to the use of side-scan sonar to study manatees.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